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COOPERATIVE RESEARCH

Edited by
Nam P. Suh
and
Bruce M. Kramer

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"Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the National Science Foundation."

COOPERATIVE RESEARCH

Proceedings of the conference sponsored by
The Laboratory for Manufacturing and Productivity
of the Massachusetts Institute of Technology, and
The National Science Foundation

Edited by
Nam P. Suh
and
Bruce M. Kramer

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PREFACE

Dr. Robert C. Seamans, Jr.
Dean of Engineering, MIT

Cooperative research endeavors between universities, industrial firms and government are being increasingly emphasized by federal policymakers. Yet little attention has been paid to the details of the cooperative research mechanism. Without such attention, policymakers and researchers alike run the risk of neglecting crucial aspects of cooperative endeavors which are necessary for success, of forgetting the dearly-bought lessons of past cooperative efforts, and ultimately, of condemning a promising means of assisting the American economy to an unmerited demise.

The Conference on Cooperative Research held at MIT in February 1980 under the joint auspices of MIT's Laboratory for Manufacturing and Productivity and the National Science Foundation brought together the leaders of academia, industry and government in an attempt to unearth and organize those elements of cooperative efforts necessary for productive research. Perhaps most important was the opportunity afforded industry executives to interact with their counterparts in academia and government and to begin to decipher the complex problems of successful research.

Judging from the reactions of the participants, the conference achieved its goal of elucidating the problems of cooperative research and started the search for answers to these problems. The proceedings which follow should serve to disseminate this base of knowledge more widely. The document is unique in that it records the advice, opinions and reactions of a spectrum of American leaders in a single volume. It is to be hoped that these proceedings, as well as the conference which they record, will eventually contribute to the development of innovative cooperative research efforts which will strengthen academia, American industry, and indeed, the country itself.

ACKNOWLEDGEMENTS

This book is largely based on the transcripts of a conference that was held at the Massachusetts Institute of Technology on February 18 and 19, 1980. The conference represented the efforts of Professor Nam P. Suh, who, at the urging of the National Science Foundation, brought together a community of academic, industrial and government leaders with firsthand experience in cooperative research for a forum with interested parties.

I think the book conveys some of the spirit of the conference. I know that the enthusiasm of the participants comes through. It is the enthusiasm that comes from successfully negotiating the first few steps. It is a call to proceed confidently in the direction of increased cooperation on the basis of past experience while accepting the uncertainty entailed in our limited understanding.

It was a great pleasure to have been involved with this effort. The opportunity to deal with the gifted people who participated in, organized and coordinated the conference itself and the publication of these proceedings was an education in the truest sense. In this regard, Jane McGarry, Sally Pendleton, Shawn Smith, and Steve Bowden of Orchard House, Inc. are the people who transformed a rambling set of transcripts into the coherent prose that you see. Ms. Karin Backlund performed the agonizing and thankless job of transcription and Ms. Barbara Weinblatt and Ms. Alice Markunas of MIT attended to all conference arrangements.

My sincere thanks and congratulations to all.

Bruce M. Kramer
Cambridge, Massachusetts
August, 1982

I. INTRODUCTION

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Welcome

Dr. Jerome B. Wiesner
President, MIT

It is obvious that the notion of cooperative research is an idea whose time has come. We are considering a problem of great interest - one that is essential for us to understand better, and one that I personally find very difficult and intriguing because it covers such a range of activities. We are trying to make the interaction between university research, industrial research, development and production, and the government more effective, and we have a number of reasons for believing that this is necessary.

It is becoming harder and harder for the United States to be competitive in a world market. At one time, an American company's effective competition in the domestic market assured its effective competition in world markets. This is no longer the case; today, products that are developed for the American market do not necessarily suit the world market as well as do products that are externally developed. The economics of our production facilities are less competitive in certain areas, a problem that used to be attributed to our high labor costs. We are slowly beginning to realize that the cost of labor is only one among a great many factors, not fully understood, that contribute to our slipping position in the world market. It is becoming clear, for example, that competition, rather than occurring primarily between different firms, increasingly pits nation versus nation; and many countries are organizing production internally so as to present a better competitive face. In the United States we have not yet learned how to do this and still maintain that the kind of internal competition we have felt for so long is important.

When people talk about an innovation lag, I find it hard to understand, because for all of my professional life I have been associated with the fast moving information, communication and computer segments of technology. (Even when I worked in the White House I felt that I was involved in information processes, if not as directly as when I worked on technical problems.) These fields have been accelerating rather than slowing down, and if there was any more innovation in the computer or the communications fields, it would be hard for us to keep up. The expanding use of satellites, the exploding use of video technology, the development of interactive computers, and the galloping advances in solid states physics and semiconductors are certainly not signs of an innovative lag. In fact, I think that the United States remains the innovative, if not the productive, leader in these fields. We need to examine why, though we remain the innovators, we are frequently not the best producers of the products that we develop. It is our production, not our innovation, that demands attention.

There was a time in this country when many felt that too much collaboration existed between the universities and government and industry. When I was science advisor to the government, I found that I was frequently explaining to the Justice Department that conflicts of interest made American activities productive; that the interaction between the universities, the space agency or the Department of Defense, and private companies, for example, distinguished the U.S. technological scene from those in other countries. I referred particularly to the easy collaboration and flow of people between the various institutions. But there has since been so much concern about potential conflicts of interest that the system has been regularized into impotence, and the synergism to an extent driven out. What we are now searching for is how, in fact, to reinstate that synergism. In those areas where cooperation was most effective the government itself was a consumer, was *the* consumer, and knew precisely (or at least thought it knew) what it wanted. The collaboration involved the universities and industry as the suppliers of information and technology, and the government as the consumer, which made for effective and creative activities.

We need to be more concerned with the interaction between innovation and technical exploitations in areas where the government is, if not a bystander, an incidental consumer and therefore not as effective in stimulating the market. Despite many attempts we have not found a process whereby federal funds can be used to stimulate R & D for the broad consumer market. This is in part because it is difficult for the government to define those products needing such stimulus when the government is not their prime consumer; in part because of the competitiveness of mature industries where innovation is necessary (the energy industry is an example); and in large measure because the government does not know how to be a sponsor of technology. I have believed this for twenty years, and continue to become increasingly convinced of it.

By and large, when the government becomes a sponsor of or tries to stimulate technology, it uses the same techniques which it has used successfully in stimulating or in supporting basic research. The government awards grants according to the quality of the written proposal rather than the need for or the opportunity offered by the proposed research. Usually the funding is disbursed in much the same way as funding for basic research is disbursed: a given amount of money is divided among the good programs. People can sometimes adjust their basic research to this manner of funding, but even in the support of basic research it is frequently ineffective. Clearly, if there is a twenty million dollar problem to solve, and instead of asking what it takes to solve it you say, "we have two hundred thousand dollars to spend," and you give it to the person who promises you the most for that two hundred thousand dollars, you are not likely to be very successful in solving your problem. This has been the nature of the government's applied research technology support. I know that the NSF has gotten tired of hearing me say this, but I do think that it is one of the core problems we face.

The cooperative research programs sponsored by the NSF have been on a larger scale, and generally have functioned in an area where there is a defined need. They have been established in an area where an industry, a company or group of companies, a university or group of universities, and the government identified a need which demanded attention. There have not been many of these programs, but they may point in the right direction.

There are clearly many other motivations for this interest in cooperative research. Our international competitive situation is one, but in other areas the need for such research is just as great. Simple mention of the word 'energy' calls to mind an area of tremendous needs and tremendous opportunities. There are far more ideas and more people wanting to work in this field than there is support; somehow we lack the organization and focus essential to real progress and problem-solving in the energy field. The complementary side to the energy issue is the area of environment and risk, where it becomes apparent that much of our technology poses risks for society. We have learned how to identify risks and maybe even how to put some numbers on them, but we do not really know how to make risk-benefit calculations. In many areas, and this is particularly true in the energy field, we are handcuffed by our inexperience with the risk-benefit issue. When some of us were younger we used to say that we were going to take a calculated risk, which meant when we had something we wanted to do, we went ahead and did it without knowing the risks. Now we have learned how to calculate such risks, but not how to calculate the balances or the risks of *not* doing something, and as a result we are in very serious trouble.

Much of the delay in some fields comes from our inexperience with the problem of risk. We are in a transition in society, from a time when we ignored the risks and paid a high price for doing so, to a time when we will be able to manage the risks. This may be the worst of all positions; we identify the needs but haven't the social processes for making the judgements, and so everything stands still.

With this particular difficulty a collaborative program can do a lot of good. By and large, individual industries whose businesses generate environmental impacts are not regarded as credible witnesses when they take positions, based on research, supporting their own business activities, and this probably will always be the case. Universities are generally regarded as more credible witnesses. If collaborative research, research sponsored by government, industry and universities together, can help identify problems and find solutions to some of the questions of risk in our society, and present them in ways acceptable to society, then collaboration can play a unique role. This informational role of cooperative research ventures is worthy of serious attention. It should be considered not only with regard to the questions of risk, where we need to generate both research and public information, but in general with regard to broader problems of technology.

I mentioned the area of energy earlier. There is probably no field today about which there is more public confusion than the energy field, yet there is also no field about which there have been more good studies. The National Academy Study on Energy, a monumental document full of information, is one, and another is the Ford Foundation study, *Resources for the Future*. But these studies are too full of information; the energy problem has many different dimensions - time, impact, economics, different opportunities - to be jammed together in a several-hundred page report. It is almost impossible for anyone, not only the general public but also the lawmakers responsible for implementing programs, to understand such reports. Possibly a cooperative program involving industry, the universities and government, the goal of which is to make the information buried in these documents more accessible and comprehensible to the public, would do even more good than a lot of new technology. I hope we can focus not only on collaborating to develop new information, but also on collaborating to make existing information better understood and appreciated.

BIOGRAPHICAL NOTE

Dr. Jerome B. Wiesner was president of MIT from 1971 to 1979, and a member of its faculty for 25 years before that. At MIT he has served as director of the Research Laboratory of Electronics, acting head of the Department of Electrical Engineering and dean of the School of Science. Dr. Wiesner was one of the founders of the Lincoln Laboratory. He is recognized as an authority on microwave theory, communications science and engineering, radio and radiation propagation phenomenon, as well as on matters of science policy and technical education. Dr. Wiesner has been a frequent consultant and advisor to government agencies, particularly the Department of Defense and the Department of Health, Education and Welfare. He was special assistant to President Kennedy for Science and Technology, and briefly held this post with President Johnson.

For eight years, Dr. Wiesner was a member of the Massachusetts Science and Technology Foundation board, where he provided advice and consultation to the governor and other officers of the Commonwealth. He has for many years been a frequent advocate of international negotiations towards effective controls and limitations on nuclear armaments as a deterrent to nuclear war.

Articles by Dr. Wiesner have appeared in numerous professional journals as well as in several popular magazines. He is the author of *Where Science and Politics Meet* (New York, McGraw-Hill, 1961) and is co-author with Abram Chayes of *ABM: An Evaluation of the Decision to Deploy an Anti-Ballistic Missiles System* (New York, Harper and Row, 1969).

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Introduction

Professor Nam P. Suh
Director, Laboratory for Manufacturing and Productivity, MIT

Sometimes simple things in life are hard to understand and rational things that make sense are difficult to implement. *Cooperative research* between universities and industry may be one of these things. Certainly the idea that the unique intellectual and institutional resources available at universities and the technological and productive basis of industry should be linked together to generate new disciplines and innovations that cannot otherwise be generated is valid. Certainly there is nothing irrational about the idea that the fundamental understanding of commonly used processes and technologies can be developed more effectively at a center that is located at a university and jointly supported by a consortium of the industrial users of the technology. It seems that such an arrangement will assure the effective use of the limited financial and human resources available for R & D. Certainly the concept that there ought to be a close relationship between universities--the generators of educated people--and industry--the user of most of the university graduates--cannot be faulted. These ideas seem to make even more sense in light of the plight of our mature industries that are faced with foreign competition. Yet cooperative research between universities and industry faces very difficult odds at all fronts.

There are some justifiable concerns one may have about implementing cooperative research. First of all, we must be certain that institutional integrity is not compromised. Universities must be able to pursue their educational and research goals free of those constraints that may be justifiable or expedient on a short-term basis but unjustifiable in terms of the long-term viability of educational goals of universities. Universities should not succumb to the pressure for short-term gains by shedding their commitment to social justice and public well-being. Industry, on the other hand, must be able to pursue its profit-motivated goals and strive for the most effective use of human and capital resources. It may be a mistake to implement the concept of cooperative research unless the program serves these differing goals of universities and industry.

As with any other endeavors of mankind, what often limits the implementation of cooperative research are practical problems, such as preconceived notions about the nature of academic research, proprietary information and the like. Whether or not these problems are real is secondary to the fact that these preconceived notions exist. Therefore, it is necessary for us to examine all aspects of cooperative research objectively and constructively so as to accentuate the positive and take necessary corrective steps to strengthen the weak points of the concept. These are real intellectual issues that require the best minds to clarify them, mull over plausible solutions, and suggest various means of achieving the desirable ends of cooperative research while minimizing any undesirable aspects. The purpose of the Conference on Cooperative Research was to examine various different formats of cooperative research, evaluate the benefits and liabilities of collaboration among universities, government and industry, and chart future directions of cooperative research. The purpose of the conference was not to develop a consensus, for there can be none in view of different aspirations of each institution and each industrial firm. Rather, the conference was organized to assess the issues involved so as to assist those interested in pursuing cooperative research.

Cooperative research is a worthy concept to consider because it enables universities and industry to accomplish tasks and generate ideas which cannot be done without cooperation. Sometimes people think that if one spends a given sum of funds for research and development, the outcome will be the same regardless of where the work is done. However, we have found that new ideas that can radically improve productivity and or quality of products are rarely created by the people who have been nurtured in a given culture. Clashing of different cultures and concepts is an indispensible prerequisite in fomenting new trains of thought. Few major innovations of the past several decades, including instant photography, xerography, the laser, and solid state devices, came from the people who were in the fields.

For universities, cooperative research is an important means of establishing a long-term research base without funding interruptions. When a large number of industrial firms jointly fund research through membership, the research program can be sustained even when the composition of the membership changes. Even when a few companies may have to terminate their membership, the program still survives. Therefore, the program can set up and pursue long-term goals, while making sure that the short-term needs of the member firms are properly taken care of through consultation and the application of research results to specific problems. This arrangement may eliminate the sad saga of American university researchers chasing after financial support, often in response to external stimuli. Such research efforts have reflected the plans of government, which were often established to achieve short-term goals and are not necessarily compatible with the long-term interests of academic and industrial organizations. The lack of long-term planning at all levels of our society has even afflicted universities during the past two decades.

For industry, cooperative research is a means of acquiring new ideas and technology at relatively low cost, a mechanism through which to expose technical personnel to external technological developments and provide continuing educational opportunities, a means of having access to technological information, and a mechanism by which industrial firms can make contributions to producing a generation of future engineers with the right perspectives and backgrounds. Even management can acquire a window through which an unbiased view on technology can be obtained.

Some of these concepts have been tried out in the United States through the Experimental R & D Incentives Program of the National Science Foundation. There have been many other attempts made in recent years to stimulate interaction among government, industry and universities. The lessons learned from these attempts should be reviewed and future plans must be made if we are to bring about a successful collaboration between academia and industry.

If the conference achieved its limited goals, it was due to the support MIT has received from many individuals too numerous to mention. Certainly the speakers and participants of the conference deserve much of the credit. Mr. Robert M. Colton and Dr. Jack Sanderson of the National Science Foundation, together with other friends in NSF who toiled with this concept, deserve most of the credit.

The proceedings of the conference are published for the purpose of disseminating the essence of the arguments, rationales and motives behind cooperative research, and also for the purpose of providing a snapshot of the ever more rapidly evolving relationship between academia and industry in the United States in the 1970's. If these proceedings contain a few data points that can elucidate the pros and cons of dynamic interactions between those who are primarily charged with pursuing knowledge and educating the younger generation and those who are basically responsible for prosperity of people, it will have served its purpose. Professor Bruce M. Kramer and his staff certainly should be pleased with the outcome of the conference. I personally owe them a great deal of thanks.

BIOGRAPHICAL NOTE

Dr. Nam P. Suh is a professor of mechanical engineering at the Massachusetts Institute of Technology, Cambridge, Massachusetts. He is also the director of the Laboratory for Manufacturing and Productivity which is the center for productivity and manufacturing at the Institute. Director of the MIT-Industry Polymer Processing Program since its founding in 1973. Dr. Suh also serves as director of the Surftech Corporation of New Hampshire.

Prior to joining the MIT faculty as an associate professor of mechanical engineering (1970-75), Professor Suh was on the faculty at the University of South Carolina in Columbia. His industrial experience includes four years of employment with the USM Corporation (1961-65), and two years of part-time employment with Guild Plastics, Inc. (1958-60). He earned his S.B. and S.M. degrees from MIT in 1959 and 1961, respectively, and received his Ph.D. from Carnegie-Mellon University in 1964 under a special fellowship established by the USM Corporation.

Professor Suh's current fields of research are manufacturing, tribology, materials processing, and cutting tool materials. Among his accomplishments in these fields are developments of new advanced cutting tools, the delamination theory of wear, the introduction of the axiomatic approach to optimization of manufacturing systems, and many new and commercially successful polymer processing techniques such as the USM process, foam lamination process, and electrical-mechanical hybrid mixing. He has also worked with the combustion of solid propellants in which he introduced the concept of thermo-mechanical effects in the solid phase reaction and a theory for super rate burning. Over 90 publications and patents have resulted from his work in addition to a textbook written in collaboration with Turner entitled *Elements of the Mechanical Behavior of Solids*, McGraw-Hill Book Publishing Company and Scripta Technica Publishing Company. A special issue of the journal *Wear* was devoted to his research on the delamination theory of wear which is also available in monograph form. He has been invited to give over 30 lectures at various universities and professional institutions.

Professor Suh has consulted for many firms and government agencies and is currently serving on the steering committee of the Machine Tool Task Force. He is a member of ASME, SPE, Pi Tau Sigma, Phi Kappa Phi, Sigma Xi, and C.I.R.P., and was the 1977 recipient of the Gustus L. Larson Memorial Award of the American Society of Mechanical Engineers and Pi Tau Sigma.

II. THE PUBLIC SECTOR

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The Role of the Public Sector and the Public Interest

Dr. Jack T. Sanderson
Assistant Director, National Science Foundation

In past decades, the federal role in cooperative research has been clearly defined in areas of defense, aerospace technology and nuclear energy--areas in which government was the consumer, no industrial base existed, the level of science and technology was high, and the R & D cost and risk precluded any single company assuming total responsibility. In civilian markets, federal assumption of risk and provision of support for the total spectrum of research, development and demonstration seems inappropriate. We must look for new solutions to today's problems. Studying the experiences of Japan, Germany and Britain, although instructive, will not answer U.S. problems.

President Carter's Domestic Policy Review provided one focus for examining these issues. Restoring and maintaining a stable economic climate, capital formation and regulatory stability must be emphasized. There is a clear need for a federal role in re-establishing the links between industry and the academic research community, both in the fundamental sciences and in areas of technology underlying major sectors of our economy.

Several federal agencies, among them the Department of Commerce and the National Science Foundation, have begun experimental programs, including University Industry Research Centers in broad areas of generic technology, university-industry research on specific topics, research support for high technology small businesses, and innovation centers to stimulate the development of a new breed of engineers. These and other new programs are examples of new cooperative university-industry-government ventures. From these experiments we can draw information on which to base further activity.

It is a pleasure to have the opportunity to share some of my views on the federal role in sponsoring university-industry cooperative research and in insuring that the public interest is served. This cooperation is important, and I will emphasize from the beginning that it is three-fold, involving university, industry and government. Even in the many cases where government is not directly involved in relationships between universities and industry, it still stands at the table as a silent partner through the rules, regulations and economic policies it establishes and in which industries and universities must operate. In general I will limit my remarks to the sponsoring of activities in civilian sector research and innovation, since precedents are well established in defense, in aerospace, and in other research and technology where the government is the major consumer.

From the historical perspective, the problem that we are addressing is fairly new. Twenty-five years ago, university-industry cooperation represented about twelve percent of university research. Today, the funds flowing into universities from industries are down to something just over three percent, although the amount is increasing at present. These statistics in themselves do not necessarily represent a serious problem, since the absolute level of industry funds flowing to universities for research has held constant or increased slightly over the same interval. Yet there are broader concerns which have come up in our general economy over the last few decades that clearly indicate the need for increased cooperation. I will discuss two types of roles for the Federal Government in this country's research and development environment. The first involves the establishment of a significant number of major cooperative technology centers, each of which would underpin a family of generic technologies that support U.S. industrial productivity. The second is the Federal Government's influence through tax policy. For example, there have been proposals to allow a direct tax write-off for industry funds flowing to university research efforts, and a direct tax credit against corporate taxes owed by the company supporting that research. In essence, an industry supporting research in universities would get a double benefit from the dollars flowing out and would at the same time be independent of any federal involvement in the decision of which universities, which projects, and what type of research to support.

One of the serious problems that has caused our concern is the changing pattern of our economy. The ten-year slowdown of the pace of innovation in U.S. manufacturing in comparison with our major trading partners and competitors is well documented. It is real, and it is a cause for proper concern. The cause, the effect, and the symptoms of this so-called "innovation lag" are bound up in a cluster of factors that have affected the U.S. economy for over a decade. These include chronic unemployment, inflation, a sluggish growth in our rate of productivity, declining international competitiveness, chronic trade and payments deficits, weakening of the dollar, and sagging public confidence both at home and abroad in the future of this country's economic leadership.

These are symptoms of more fundamental changes that are taking place in the United States and the global economy, changes which are going to require the continuing evolution of the role of the partnership among universities, industry and government over the next few years. Basically, these changes revolve around a number of key decisions made, perhaps unconsciously, in the sixties and seventies, to achieve social objectives not reflected in the marketplace. Dr. Wiesner mentioned earlier the great concern for avoiding risk. Not only in U.S. industry but throughout all elements of our society there has been a push for environmental improvements, a push for greater equity for all citizens of the country. These are desirable goals, which will continue to receive public support and represent a significant element of the public interest. But these drives also have real costs associated with them, in terms of regulatory complexity and uncertainty in the marketplace. There is a real price for environmental cleanup and the achievement of social objectives. In response to these, many companies over the last few decades have been forced to turn towards more defensive research. These social movements have greatly increased the uncertainty and risk associated with the long-range innovation and discovery that leads to the marketing of new products, which has been a keystone of the U.S. economy.

A second factor is the move towards what has been described by some as the value-added economy. We have gone from a reliance on domestic sources for raw materials, and the domestic manufacture and sale of products, to increasing competition on a global basis for both foreign markets and foreign sources of raw materials. Energy is the most obvious example. In addition, our U.S. markets are being penetrated more and more by foreign competitors, and in many cases we are finding it difficult to keep up. A typical U.S. auto manufacturer, for example, makes about twenty-five cars per worker per year. This compares at present with some forty-nine cars per worker in a Japanese auto factory.

The increasing complexity of science and technology is a third factor that will force the government, industry and universities to reevaluate their stances. As science and technology grow more complex, there is added risk in sponsoring the broad base of research needed for new innovations. The cost is larger, the time constant for a major new innovation is now ten years or so, and there is a steadily decreasing likelihood that the company sponsoring the initial research will be able to capture its benefits fully. Some of the studies we have sponsored show that, on the average, society gets about twice as much benefit out of a new innovation as does the company which makes it. So we can argue that there is a societal role and a societal interest in sponsoring research and innovation.

In many cases I would argue that more attention should be paid to that critical area between basic research, which is published in the open literature and available throughout the world, and the development of a specific innovation by a private company. This is an area which has been described by some as good fundamental engineering research, by others as the support of generic technology. Overall, the need for a closer look at these areas has led to advocates for a wide range of solutions. There are strong advocacy groups both for a substantial withdrawal of the Federal Government from regulation and intervention in the marketplace (including some forms of taxation), and for the creation of a U.S.A., Inc., led by government policymakers, to provide direct competition with

Japan, Inc., Germany, Inc., or whatever the competition may be. My personal belief is that neither of these answers is going to work. They are not realistic. There is no way that society -- the Federal Government -- can or wants to draw back from many of the social objectives that have been achieved over the past two decades. If you do not believe that, simply look at Lake Superior or Lake Erie and ask yourself if you would like them the way they were twenty years ago.

At the same time, it is important to realize that the U.S. economic system is fundamentally based on free enterprise, on the use of the marketplace to reward risk and punish failure. Any public policy changes supported by the NSF or others should be designed to strengthen these characteristics, not to weaken them. We must find the mechanisms that the public sector can use to stimulate innovation in the private sector without forcing distortions in the public marketplace.

We are not without some examples of ways to do this. I will describe a few that we have experimented with, and some that others have tried. One of the earliest examples was direct federal support of basic research. Dr. Wiesner mentioned that it was perhaps not as much and not as well managed as we would like. Nonetheless, we have built in this country, through the support of basic research, a strong scientific enterprise that is, by any measurement -- Nobel prizes or whatever -- a leading capability of the country. This clearly needs to be strengthened. This country's educational needs in the sciences and engineering have been brought home as a problem that is perhaps akin to one that we had in the early sixties, based on recognition of the declining scientific capability of the average student in the United States, and the increasing technological and scientific capability of many of our competitors. At the present time, a Russian student graduating from high school has had two years of calculus. Compare that with test scores in the United States, where many high school graduates cannot balance their checkbooks.

Much attention in the recent domestic policy review on innovation has focused on developing generic technologies, those broad capabilities that underlie major sectors of U.S. industry. As I said earlier, on closer inspection many of these areas look like good fundamental engineering research, materials research or research in some of the other physical sciences. I personally believe that there is an increasing awareness of the need for the NSF or other organizations to strengthen their programs in engineering; for the Federal Government to accept responsibility for fundamental research support across all of the engineering disciplines in the same way that it has accepted responsibility for the support of astronomy, the physical sciences and the biological sciences.

We need to reestablish the university-industry cooperation which has existed throughout most of the history of this country. The NSF has experimented with a variety of mechanisms. Some of these have been identified as models that can be strengthened and expanded throughout the Federal Government.

The industry-university cooperative research program of the National Science Foundation has been proposed for substantial increase, from about a $14 million program in this fiscal year to a $40 million program in the next fiscal year. The model for this is a one-on-one, project by project basis; one company, one university, one project, working across all of the disciplines in research areas supported by the NSF. It is a program in which the NSF will provide, with normal cost-sharing by universities and by industry, dependent on the size and the capability of the industry, most of the support needed for individual research projects.

A second model that we have experimented with is the university-industry cooperative center, a form of the generic technology centers. NSF has concentrated on centers established at major research universities involving groups of cooperating industries and based either on a particular industrial technology or on a particular area of research. In general, the NSF starts a center, provides research support during the critical years of birth, and allows time for the center to establish its identity. Over a period of years the NSF support is withdrawn and the center becomes a self-supporting institute on the university campus, with industrial funds providing the salaries and the cost of the research. One of the best examples of this is the MIT-Industry Polymer Processing Program, with Dr. Nam Suh as director. The NSF has not been supporting that project now for several years. It has run over a hundred different research projects, has trained many graduate students, and became within five years of its start completely self-supporting. Currently the program is operating with a half-million dollar a year research budget. The number of participating companies during the first five years grew from three to twelve.

There are other examples related to these cooperative centers. At Cornell, the Foundation established the National Research and Resource Facility for Submicron Structures in 1977, with a five-year, five million dollar grant. Cornell has already increased its cost-sharing to $800,000 and has established a building program for the facility that will cost about $3.4 million. To date, twenty-nine projects have been approved, projects such as the fabrication of electrodes for nanosecond electrochemistry studies and for the study of quantum size effect in small metal particles. Research and graduate training is contributing to the national effort in developing very small scale, very large integrated circuits. Other major universities and major companies, along with Cornell, are participating in this program, which has generated worldwide interest. Although the NSF has supplied major research support, the center at the University of Delaware for

Catalysis was established in 1977 by the university itself to provide a national focus for research and education in the fundamental science and application of catalysis. Each of thirteen participating companies are now providing about $25,000 a year to support a broad range of research directed towards the national concern for energy resources, alternate chemical feed stocks and environmental problems.

The National Science Foundation has experimented with a series of innovation centers, one here on the MIT campus. These centers are designed to approach another problem: the problem of educating engineers and business school graduates who are interested in becoming entrepreneurs, leaders of high technology companies, or leaders of small businesses based on high technology innovations. In the fall of 1980, the Foundation and the Department of Commerce held a major conference of engineering and business school deans to examine opportunities for joint curricula, to see if we can reduce the sensitivity to technological risk of many business managers. The conference was designed to improve communication between the innovative engineering scientific community and the business leaders who, all too often, are focused on short-term, sure return on investment.

If we look at still larger university-industry-government interaction outside the areas of defense, health and space where the government is the consumer, the federal agencies are moving much more slowly. Some people will argue the effectiveness of the federal intervention in the nuclear energy effort. You will find less disagreement perhaps and more support for the older National Advisory Committee for Aeronautics program. I do not at present see another NACA or the mechanism to form one, even if we identified appropriate needs, but there are new programs beginning which can represent major experiments in large scale cooperation, and provide a model for further cooperative research.

The National Science Foundation has organized a team of academic and industrial scientists in the first phase of a ten-year, $700 million program for deep sea drilling, designed to produce geological, geophysical and other information related to the ocean margins. Called the Ocean Margin Drilling Program, the effort involves conversion of the 618-foot, government-owned *Glomar Explorer* into a ship capable of meeting the long-range objective of drilling in water up to four miles deep. The NSF budget request for this program is expected to be matched by an equal contribution from the oil companies. During the first year, we concentrated on technical design, engineering studies, science planning, site identification, and cost estimation. We hope to have the ship converted and drilling started by 1984. This program represents a rather attractive convergence of several areas including the fundamental geophysical sciences, the technological development of new techniques for drilling in deep water and the exploration of some offshore areas of promising geological construction.

The primary thrust of this conference is to examine ways to improve synergistic interaction. I would be remiss, however, if I did not emphasize that the primary thrust of all this collaboration, at least in the programs which I have described so far, has been to strengthen scientific and technical capability in the United States. That capability ultimately has its payoff only when it is adopted by U.S. industry and brings innovations into the marketplace. Without a strong innovative private sector we will be in trouble over the long term. Here, many of the issues related to tax regulation, patent and antitrust policy lie beyond the responsibility of the NSF. While we will continue to monitor these issues and even to comment on them in the Congress and the Executive from time to time, we are simply one more player in the large arena. In one area, however, we have been identified for a substantial program with the private sector. That is the expansion of the Foundation's small business innovation solicitation. This program funds small businesses that are involved in high-risk research (where money is never available) to get them into the later developmental stage, where venture capital usually can be found. It is a program which we plan to expand by about a factor of four during the next fiscal year.

In conclusion, I would like to sum up my remarks by saying that there are substantial changes going on, in both U.S. society and the external environment, which will require us over the next couple of decades to rethink the structure of and policy towards cooperative research. University-industry cooperation will be a major component in strengthening the innovative and technological capability of the United States. Although, ultimately, much of this cooperation must be based on direct efforts between universities and industries, the government has a significant role, both in defining policies to create the environment for university-industry cooperation and in the support or initiation of selected cooperative programs in selected areas, such as generic technology concerns.

Finally, despite some highly visible successes, the wide range of cooperative research efforts needed, the difficulty in identifying and in justifying the proper federal role and level of support in each specific case, and the long, often difficult negotiations that have to take place to get any one major program started, our experience clearly indicates the benefit of and the need for conferences such as this to develop more general guidelines.

Questions

Questioner not identified: How do you propose to measure the success of these cooperative centers as far as actually producing results?

Jack T. Sanderson: We have defined several measures of success. One measure is the number and success of products or new technological capabilities which clearly come from these centers. In the case of the innovation centers, new companies formed either while a person is at the center or is working in conjunction with the center may be taken as a measure of success. But I think that the fundamental Foundation attitude is that success will be proven by survival. The federal role in the centers that the Foundation proposes to start will be to provide funding to get things started and, over a period of time, to withdraw. I expect that we will lose some -- if I thought we could get one hundred percent success I'd be in a different job. But the object is to win more than we lose, in the context of a ten-year survival rate. By that criterion we can certainly win.

J. H. U. Brown: Would you care to comment on the relationship between industry and the government patent policy, and the licensing of patents to universities under these cooperative programs?

Dr. Sanderson: That is an area receiving more discussion in Washington now than I can summarize briefly. There are several patent bills which have been introduced within the last year. In general, the tone of the patent bills has been to assign to universities and to small businesses absolute patent rights, with certain provisions for government march-in if the ideas are not developed. In some of the bills, assignment is limited to a defined set of areas in which the discoverer can identify areas of application; in other bills, it is a general assignment. I would say that the chance of something getting through Congress over the next few years is fairly good, but there is still enough disagreement on the particular form of the bill that will get through that I would hesitate to predict the specific outcome. I think that universities and small businesses definitely stand to benefit.

John Bernard: At present there are two bills in Congress, the cooperative technology bill and the Vanik Bill. How do you rate their chances of passage with the present mood of Congress and the President and so forth?

Dr. Sanderson: The Stevenson Bill, which contained a number of provisions intended to strengthen our ability to understand foreign trade and to authorize the establishment of a number of generic technology centers, was introduced before the results of the President's domestic policy review became public. I have not seen any strong push at the present time to bring that bill off the table and start moving it forward. This is, at least in part, because both the Department of Commerce and the National Science Foundation already have the authority to start the cooperative technology centers which were highlighted in that bill. The Vanik Bill is a fairly new introduction, and I cannot even begin to guess what its fate will be. That will depend in great measure on the public reaction to it over the next few months. I would say, however, that there is a heightened sense of the need to do something in this area in Congress, more than I have ever seen in my time in Washington. Congress is actively looking for positive steps to take. Whether these steps will crystallize around the two bills, I cannot say.

Arnold Kossar: I recently completed service on the Domestic Policy Review on federal regulation and innovation. I think that we should not characterize the incompatibility of innovation and regulation as extreme; the industry position is hardly that. Inherently, value judgements are involved when examining the very small incremental positive effects of regulations as countered by the rather gross effects of the regulations on innovation. I just want to stress that, in the particular case of the Subcommittee on Environmental Health and Safety on which I served, nobody in any way suggested that the societal objectives are not pertinent and enduringly worthwhile.

Dr. Sanderson: You are completely right. I think, in fact, that there is probably more discussion about backing away from regulation among the bureaucrats than there is among industry. The comments I have heard from industry are not directed towards retreat. Most industrial leaders say that they will live with the rules if the government will make them and leave them alone. It is the uncertainty and the changing regulations that seem to be causing a lot of the problems.

Rudolph Yobs: In this tripartite arrangement for cooperative research it is probably easiest to maintain the interest of government and the universities. Trying to maintain the participation and financial contributions from industry is the most difficult part. As a policy matter, has consideration been given to the continuation of matching fund policies to maintain industry participation?

Dr. Sanderson: That depends on the particular area of cooperation. Certainly with the project here, the Polymer Processing Center, the NSF started the program with the intent of getting out. If Nam Suh could not persuade his industrial sponsors that he was worth the money, then Nam Suh had a problem. In some of the other centers, the Cornell Submicron Facility for instance, we anticipate that the character of the research there and the interest in it is probably more fundamental than industry will ever be willing to support fully. Therefore, I do not foresee any pulling out of NSF support for that activity in the visible future. Clearly, each of these centers has a flavor which depends upon its relationship to the industrial partners involved, and upon where the center fits within the industry.

We are talking about a very broad spectrum of activities, some of which industry is very excited about staying with over the long term. Indeed, in some discussions of the Ocean Margin Drilling Program, the point was made by an oil company that industry can commit its money, while the NSF has to be reappropriated every year.

There are questions on both sides about the duration of commitment.

Donald Buyske: It seems to me that we can all agree to the urgency for cooperation among universities, government and industry, but the money that you are talking about is rather minor. Fifteen to forty million dollars is a drop in the bucket, if we really accept the necessity of cooperation and believe we should get on with it. Would you comment on that?

Dr. Sanderson: The level of effort in this phase is clearly experimental. At one point in the President's Domestic Policy Review recommendations, the proposal was to expand the industry-university cooperation to about a $150 million a year program, and to expand -- government-wide, not necessarily in NSF alone -- the small business program to about the same level. The focus on encouraging this cooperation is still new enough that many policymakers, certainly many budgeters in the Federal Government, feel that we ought to go slow and learn a little bit as we develop with the objective of growing. I think there is also a strong sentiment in many parts of Washington towards finding ways to do this without direct federal funding; ways to change the environment so that universities and industry want to get together. There are good models -- the classic one that is always discussed is the Harvard-Monsanto arrangement, but mentioning that program alone is an injustice to a lot of others. For example, there is the Delaware Center, which was started without a conscious federal decision, and there are a number of other programs here on the MIT campus. So the current plan is to work towards a mixed strategy of direct federal support in some areas, and to provide the environment for university-industry cooperation in other areas. Also, I have not seen a cost-out of the Vanik Bill -- that may, in fact, represent a very substantial amount of money.

Richard Alben: There is a difference in the style of research support at the NSF and at other government agencies. The NSF seems to aim more often at supporting an activity rather than acquiring a specific deliverable end item. The mission-oriented agencies often have been acting as customers; as you said, they set their contract spec and want an end item delivered.

Now, looking ahead to further involvement in this kind of cooperative research effort by the NSF and perhaps also by the mission-oriented agencies, do you see a natural split in responsibility between the NSF and these other agencies according to this difference in style, or do you think the style will be blurred across agencies?

Dr. Sanderson: I think it would be a real mistake if the style got blurred across the agencies. One of the safeguards in the whole federal system is that each of the agencies has its own technique for selecting the research and the projects it will support. I view that as a safeguard against any particular style of research becoming dominant to the exclusion of others. So, I argue that it needs to be kept diverse. But I am arguing that we currently have a gap. The Department of Commerce has made a real effort to identify some of the areas of that gap, and the National Science Foundation, with some of its small experimental programs, has tried to find ways to work on it. That gap really lies in the area that is at the heart of this conference: that is, how to deal with the private industrial technology base underlying the economy. We are pretty good at dealing with the defense aerospace industries. If we look back, we did a good job with NACA in dealing with aircraft manufacturers and aerodynamics, but we do not seem to have developed the capability for the Federal Government to support the sort of broad manufacturing capability that industry needs in order to compete internationally.

Frank Laxar: Some small, high-technology businesses claim that they are being undercut by the government support of university, not-for-profit research. Is that a contradiction or a paradox? Would you comment on this?

Dr. Sanderson: This has to do particularly with some programs, including some by NSF, which have established either regional research facilities or instrumentation research capabilities that small companies view as direct competition to testing labs or consultation research. In general, these centers have adopted the policy of being open, on a reasonable basis, to anyone with a good idea. This is a risk. It is one that we have been working with in a number of the associations of small industrial testing labs over the last year. I think that the answer ultimately is to work out some fair pricing mechanism. This is necessary particularly for industrial users, so that we are not undercutting the small business community.

BIOGRAPHICAL NOTE

Dr. Jack T. Sanderson became Assistant Director for Engineering and Applied Science (EAS) of the National Science Foundation when this directorate was established on July 1, 1979. Dr. Sanderson had been Assistant Director of the NSF's Directorate for Applied Science and Research Applications, which merged with the Engineering Division to form the Directorate for EAS.

Dr. Sanderson had previously served as Assistant Director for Research Applications, Director of the Office of Planning and Resources Management, and Acting Deputy Assistant Director for Science Education. Before joining the Foundation in 1971, Dr. Sanderson had been lecturer, Director of the Cyclotron Laboratory, and Assistant Director of the Physics Laboratories at Harvard University.

Dr. Sanderson's primary research areas have been in solid state physics, especially nuclear magnetic and electron paramagnetic resonance, low temperature and nuclear orientation. He has also done experiments in high-energy proton and electron scattering.

Dr. Sanderson received an A.B. in physics and chemistry at Harvard University in 1958 and was awarded a master's degree and a Ph.D. at Harvard in 1967.

Cooperative Research: Precedents and Priorities

Dr. Arthur L. Malenfant
Vice President, Instrumentation Laboratory, Inc.

The essential element in a research activity is taking risks; the competitive advantages which result from taking risks provide the incentive for the research activity. Basic research is primarily the province of universities -- its long-range payback makes it impractical for nearly all industrial concerns. Applied research is the province of industry, because of its rapid payback and lower risks. There must be a middle level research activity with good potential payback and medium risk if innovation and technology transfer are to thrive. Cooperative research has been conducted in several ways. Traditionally, government agencies like the NSF have funded basic research efforts in universities. More recently, innovation systems in both universities and industry settings have also been funded by government agencies. In defense-related areas, government has often funded industrial research efforts, with and without university participation. Cooperative research must address productivity, insure timely and extensive technology transfer, and perhaps most important, maximize innovation. This can be achieved through properly planned research programs which are part of an overall, long-range set of goals. The steps involved in developing an effective cooperative research program are: 1) establishing a priority for a specific research area, 2) providing initial incentive for industry to take risks, 3) bringing together the individual groups on a common ground for conducting the research, 4) developing the specifics of a project through a "common denominator" participant, 5) maintaining the interaction until the participants are stabilized in it, and 6) monitoring the activity's productivity continuously to further refine the process. The basic principles include providing incentive for risk-taking, requiring financial commitment from participants, and achieving objectives within a time frame. Industry-university interaction, mediated and supported by the government, poses the best opportunity for research programs that will improve productivity in both the short and the long term.

I would like first to indicate the perspective from which I write: I am associated with one of a number of small to medium-sized high-technology companies in the Route 128 area of Boston. As a high-technology company, we have a continuing obligation to investigate the best available technology in both the development of existing product lines and in appropriate expansion into new product areas. I will focus initially on the nature of the particular research I am discussing, and will then move on to examine the opportunities for cooperative research, the precedents for such ventures, and the priorities which are the rationale for successful projects. My emphasis is on applied industrial research rather than basic research, since basic research is primarily the province of the university and the largest industrial concerns.

The essential element in any research activity is that of risk-taking, and historically, the time required to pay back on basic research makes such activity impractical for those companies who concentrate on innovation in new product areas. The functioning R & D group in a company must analyze with care the opportunity to be gained from a particular project in order to direct resources properly into projects that will serve the corporate needs. The R & D group must then assess both the risks and the amount of invention or innovation required to achieve the established goals successfully. Since the resources in any organization are finite, this requires, in addition to a careful evaluation of each project under consideration, a careful setting of priorities among projects. If its effect is to be long-term, the research must develop the technology available to the company. Lower risk activities, such as an improvement in the yield of a particular process, will not result in the productivity improvements, competitive advantages, and real innovation which higher risk-taking in research produces.

Applied research is the province of industry; the results of such activity, if properly implemented, pay back rapidly, and the possibility of total failure is much reduced as compared to that in basic research activities. However, innovation is likely to suffer, and technology transfer from basic to applied research may be difficult, unless there is a middle level of research activity both with good potential payback and of higher risk than an individual company or even industry can absorb. Here lies opportunity for cooperative research.

Government clearly has a place in supporting cooperative research ventures, as it does in supporting basic research activities. The President's Industrial Innovation Initiatives issued in 1979 include a discussion of the government-generated economic incentives necessary if R & D is to be carried out by industry. The importance of the development of these initiatives cannot be understated; it involved eighteen months of planning by twenty-eight federal agencies, 250 government officials and 150 representatives of business and industry. Their charge was: "What actions should the Federal Government take to encourage industrial innovation?" Subcommittees focused on several topics, including environmental health and safety regulations, procurement and direct federal support of R & D, regulation of industry structure and competition, patent and information policy, and economic and trade policy. The initiatives address several areas. Specifically, they offer proposals to 1) enhance information transfer via federal technology centers, 2) increase technical knowledge by means of generic technology transfer centers, 3) strengthen the patent system by allowing the issuance of exclusive licenses to companies for federal technology, 4) clarify antitrust policies, 5) aid small innovative firms.

6) open the federal procurement mechanism to innovations by developing performance criteria that establish the relative merit of competing designs, and by looking at operating costs as well as purchase costs of equipment to be purchased by the Federal Government, 7) improve the regulatory system, 8) aid in adjustment to technological change, including a forecasting system of industrial changes, and 9) maintain a supportive environment for innovation.

The program would include a national conference on innovation, Presidential awards, and the removal of legislative and administrative barriers to innovation. The promulgation of these initiatives clearly indicates that the United States government is interested in supporting the innovation process, and is willing to make changes in its operation to do so.

In Japan, which has an excellent reputation for innovation, the relationship between government and industry is long-standing. A number of factors have resulted in the Japanese success in penetrating outside markets. First, Japanese industry is export-oriented, in contrast to United States industry which is oriented towards domestic sales. The Japanese government focuses on helping industries to compete against other countries, although it is reluctant to foster competition within Japan. This relationship between government and industry, the organizational design of Japanese companies, the propensity for risk-taking and the reward structure in Japan all contribute to the result that more U.S. patents are issued to Japan and to Japanese inventors than to any other foreign nationals. At the same time, Japan expends a slightly smaller percentage of its gross national product on research and development than does the United States. In Japan, the ratio of industrial to governmental R & D funding is approximately 68% industrial, 32% governmental.

Germany ranks second to Japan in U.S. patents issued to foreigners. At 2.4% of GNP, the German expenditure on research and development is slightly greater than that of either the U.S. at 2.2% or that of Japan which spends slightly less as a percentage of GNP that the U.S. In Germany the ratio of industry to government R & D funding is 62% to 38%, while in the U.S. this ratio is approximately 50:50, with slightly more R & D being funded by the government than by industry. German government cooperation tends to be in funding R & D rather than in developing jointly funded programs.

In Israel, depending on where a company locates, there are R & D incentives to support up to 80% of the cost of industrial research and development for "approved enterprises." The criteria used for approval of enterprises include the expected rise in product value, the development of technology, and, more significantly, a high export potential. However, the inflation rate in Israel is extremely high and the government funds research on a reimbursement basis. The result is that, although one may accurately forecast the cost of doing R & D, the amount repaid to industry by the government is substantially less in actual value than the original funding, which was established in Israeli pounds. This problem, coupled with bureaucratic delays in actually issuing the reimbursement, makes Israel's approach to research funding less than attractive as a model. The selection process is also somewhat faulty, with the result that a great deal of the funded research yields products with extremely limited market potential. The Israeli experience is not without merit, but it does point out the deficiencies in using this technique to provide a cooperative research plan.

In the area of cooperative research between universities and industry, MIT exhibits a sound series of programs which deserve attention. For many years, MIT has had a technology transfer program called The Industrial Liaison Program, which provides the incentive for industry to interact with the faculty and staff at the Institute. I have participated in a number of these programs and have found them to be very helpful. (Because of our corporate size, Instrumentation Laboratory actually belongs to the Associates Program, which is designed for somewhat smaller companies than those generally found in the Industrial Liaison Program.)[1] Additional cooperative programs at MIT involving industrial support are the Center for Information Systems Research and The Sea Grant Collegium, which is part of the Sea Grant Program.

In the area of government-sponsored cooperative research, one of the more significant programs has been the National Science Foundation R & D Incentives Program. Three of the projects funded under this program are the North Carolina State University Furniture R & D Applications Institute, the MIT Polymer Processing Program and the MITRE New England Energy Development System Center. Their primary purpose was and is to link university R & D with industry needs. The North Carolina State University program was designed to create a mechanism to join the research capabilities of the university with the research needs of a fragmented, traditional industry. The companies involved ranged from those considered to be innovative in their field to those considered not innovative. Unfortunately, this program was initiated just prior to a major recession, resulting in less participation than might otherwise have been expected.

The MITRE New England Energy Development System Center was different in concept from the other two projects. MITRE served as a broker between organizations with R & D expertise and energy-related companies requiring access to that expertise. Barriers to the success of the project became apparent when MITRE requested funding for a project from a utility. Legal regulations dictated how much of a utility's budget could be invested in research and development, as well as how much of that investment could be passed on to the consumer through increased utility costs. As a result, the efficiency of the program was compromised.

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[1] Editor's Note: The Associates Program has now been integrated into the Industrial Liaison Program.

The original objective of the MIT Polymer Processing Program was to develop a cooperative R & D venture with companies involved in the polymer processing industry. Currently, the program is technically and financially viable. In this program one finds, I believe, all of the elements of a successful research and development activity, including the necessary risk-taking. The individual projects undertaken do more than simply attempt to increase yield; they aim to provide innovation to the polymer processing industry. The program necessitates interaction between the industrial and academic members of the team, and, because the number of projects of interest is greater than the resources available, priority setting is a necessary and ongoing activity. The priority setting and interaction among participants provide the environment to insure both innovation and commercially viable ideas.

A review of the process which established the MIT Polymer Processing Program provides an outline of the specifics for a successful cooperative research venture in the future. Initially, the Institute established the priority of a need for research in a particular generic area of technology, in this case the processing of plastics. The government, through the National Science Foundation, agreed to bear the initial risk-taking cost, ordinarily borne by industry, so that the research project could reflect real industry needs. Government support was continued until the participants were stabilized in the relationship. Because the program was undertaken by a university and at a university, individuals from many separate organizations could come together and interact. This aspect of the program is extremely important, since the individuals involved interact not only in regard to the program projects but also on a personal level. Each of the specific research projects is developed by both the industrial members and the university participants, with the university serving as the final arbiter of which projects will be pursued. After cessation of government support, government continued its involvement through the continual monitoring of the process to check productivity. The ongoing process of monitoring productivity is extremely important; its role cannot be overstated.

In summary, I would like to point out the requirements, in my view, for a successful cooperative research venture. The first step in the process is the establishment of a priority for research in a generic research area. It is important to address a research area, since it is unrealistic to expect companies who are direct competitors to work together. On the other hand, companies with objectives as diverse as the manufacture of automobiles and of blood gas analyzers, for example, can be brought together to work on problems associated with the processing of polymers.

The next step is to provide incentive for taking risks. This is supplied by government funding of the initial stages of the program, and allows for both more innovative projects and the time for the program to demonstrate its feasibility. The level of risk-taking, and the potential payoff, should be higher than those which any individual member might undertake or incur alone.

The other element essential in keeping the attention of program members focused on program activities is the requirement of a financial commitment by the members. The benefit here is twofold. First, the investment of funds, as well as staff time, will necessitate review and evaluation as an ongoing process. Second, the fact that the money invested is being leveraged significantly by the participation of other members will encourage greater participation on the part of each investor.

The focus of the project must be on research with significant innovation. This kind of activity will insure the involvement of the best people from the university, and will provide higher potential payback for successful projects. The interaction between industry and the university in stimulating areas of mutual interest is the goal that cooperative research efforts must be designed to fulfill.

Finally, the productivity of the process must be monitored constantly. It is just as important to know when to stop a program as it is to know where to go next in continuing a program. In addition, optimizing effective programs will illuminate the probable viability of proposed new programs.

Questions

Marvin Goldberger: I would like to describe another model for cooperative research activity, one different from those, like the Harvard Monsanto agreement, that have been described today.

At Caltech we have a program called the Silicon Structures Program. It is a collaboration of seven companies which are clearly head-to-head competitors in some sense. They include companies like IBM, Xerox and Hewlett-Packard, and are concerned primarily with the development of very large-scale integrated circuits and the design of computer architecture and software to utilize evolving technologies. Each of these companies contributes $100,000 a year and sends one or more people to Caltech as visiting professors. These professionals are involved primarily in the research activities associated with the program. We have managed, somehow, to solve some of the problems in the program associated with restraints, patents and the like to the satisfaction of these companies.

I do not think I will take the time now to go through the details of the agreement, but if any of you are interested I will be happy to supply you with a copy of them.

This program, to the best of my knowledge, had no input of government funds to get it started. It is now in its second year, and there are three additional companies interested in joining the activity. I think that it is an interesting model which conceivably could be followed in other areas that deal with a fundamental technology of use to a rather broad spectrum of industries, who feel that their competitive advantage is served by being in on the ground floor in the development and who benefit from the interaction with people in the university community.

Wayne Morris: Do you think that public universities could handle the same type of program?

Dr. Goldberger: I do not see any reason offhand why they could not, but my whole experience has been with private universities.

Daniel Drucker: I may have an answer to Wayne Morris' question.

At public universities (the University of Illinois comprises my present and only real experience with public universities) it turns out that companies are indeed willing to cooperate. We have a valuable cooperative fracture control program which predates most of the programs that you have heard about. A dozen companies participate, but they are very reluctant, even though they are very large companies, to give more than something on the order of $15,000 a year in cash. So there is a distinction between public and private universities.

I wonder whether in dealing with MIT or Caltech instead of Berkeley or Illinois one is dealing primarily with value received, or to some extent dealing instead with philanthropy?

Arthur L. Malenfant: I would say that in dealing with the MIT program, we are very definitely dealing with value received. The amount of money that Instrumentation Laboratory is required to contribute to participate in the program is not inconsequential to a company of our size. If we did not feel that we were getting full value from our investment, we would definitely not have participated for as long as we have.

BIOGRAPHICAL NOTE

Dr. Arthur L. Malenfant received a B.S. in chemistry from the University of Rhode Island in 1960. After spending three years as a research analytical chemist with Corning Glass Works, he entered MIT as a candidate for the Ph.D. degree in analytical chemistry. After graduating in May of 1967, he took a position with Instrumentation Laboratory Inc. in their Research and Development Department. Subsequently, Dr. Malenfant formed and managed the activities of the Technical Services Department within the Biomedical Marketing Division of the company. More recent positions have included Vice President, Corporate Development. His current title is Vice President, International. In this role Dr. Malenfant is responsible for sales of all product lines of the company in Canada, Latin America and Mexico, and the Asian-Pacific area, including the People's Republic of China.

Public Policy and the Innovation Process

Dr. Courtland D. Perkins
President, National Academy of Engineering

According to many, a deterioration in our innovation climate has contributed to the decline in this country's world trade position. Innovation is that spectrum of activities extending from invention and creativity at one end, to new product development at the other. The many studies of our innovation problems over the last 15 years have had, until recently, no impact. The continued decline of our economic vitality has finally gotten the attention of Congress and the Executive Office, and we now have stated Presidential Initiatives and several hundred bills presently in Congress dealing with public policy changes to improve the situation. We should, therefore, focus more on concerted advocacy activities and less on studies.

Most of the studies undertaken and public policy initiatives recently published focus on the developmental or entrepreneurial end of the innovation spectrum. It is less evident that changes in public policy can affect our creative environment significantly. The flow of new ideas is traced from universities, industry and government organizations. The university-based research laboratory with creative faculty, excellent graduate students and first-class facilities is particularly important. If a creative environment with strong motivating potential can be developed, industrial interest will be more or less assured and little change in public policy will be required. A viable quid pro quo *between the university research group and industry is the major requirement. The Laboratory for Manufacturing and Productivity at MIT is a case in point.*

The subject of "Public Policy and the Innovation Process" creates concern today at nearly all levels of our national life. The public focus on innovation as a problem has emerged as a result of our growing economic problems and loss of competitive edge. These are measured by a negative balance of payments, the decline of the value of the dollar, and the diminishing vitality of American business enterprise. Our deteriorating position in world trade is thought by many to be the result of a decay in the 'innovative environment,' and we are frustrated by our inability, so far, to remedy that decay. This problem has become severe enough to receive high visibility and priority at all levels of the government -- it is probably just behind the issues of defense and energy in national prominence.

There have been many studies of the innovation process, with considerable disagreement over the nature of the problem and the means to improve our national position with respect to it. There is general agreement, however, on the definition of innovation. Most will agree that innovation is that spectrum of activity covering invention and creativity at one end, and the successful introduction of new products based on new invention at the other end. The two ends of the spectrum, the inventive and the entrepreneurial, are very different, and public policy will affect them differently. There are difficulties at both ends of the spectrum, but most of our attention has been focused on the entrepreneurial end. It is essential that we consider our shortcomings in inventiveness and creativity as well.

The total innovative process from invention to successful product is not usually a continuous one. It is rare for the inventor of a new capability or a new departure in technology to be able to transfer this technology to the entrepreneurial arena and properly exploit his new invention. It is more usual for the entrepreneur to seek new ideas from many sources and exploit them in a profitable enterprise. We have many examples of such discontinuity. The great invention of the gas turbine during World War II was made by an Englishman (Whittle) and a German (von Ohain). Their new invention was picked up by Pratt & Whitney and General Electric in this country, who continued its successful development and exploitation and now dominate world sales. Our invention of the transistor (Bell Labs) was adopted by the Japanese, who developed certain aspects of its use, including television (also our invention) and now compete successfully with us in several important areas. In other cases our own ideas are developed rapidly enough to keep one step ahead of the hungry entrepreneurs in other countries; this happy exploitation of the full innovation spectrum has occurred in the airplane and large-scale computers fields. Just as important as the ability to be inventive and creative is the ability to transfer new inventions into the development and successful exploitation of new products.

As I mentioned, there have been many studies from different sectors of various aspects of our innovation process. Although agreement on many aspects of the problem has been reached, and numerous recommendations for action have been made, there has been almost no progress until recently. One of the first studies to attract widespread attention was made in 1967 by a group under Dr. Herbert Hollomon, then Assistant Secretary of Commerce for R & D and now of MIT. His advisory committee, CTAB, conducted a large study chaired by Dr. Robert Charpie, president of the Cabot Corporation and then a member of CTAB. The results of this study highlighted the basic character of the innovation problems and made many recommendations, none of which were acted upon. Since the Charpie report, numerous other studies have been made, and have come to the same conclusions, with equal impact on the national scene -- none at all.

The National Academy of Engineering, under the chairmanship of Dr. Arthur Bueche, Senior Vice President of General Electric, conducted a study of these studies in December 1979 in an attempt to highlight their common findings and to delineate actions for the immediate future. Its purpose was to assist the Carter Administration, which recognized the problem and made the first steps to influence public policy in these matters.

President Carter's Assistant Secretary of Commerce for R & D, Dr. Jordan Baruch, and Dr. Frank Press, the President's Science and Technology Advisor, under specific instructions from the President undertook a massive review of the innovation problem in a "Domestic Policy Review" starting in April 1978. This review involved groups and individuals from industry, academia and labor. The culmination of the study took place on October 31, 1979, when President Carter issued his "Industrial Innovation Initiatives." The President indicated that his Administration would take action in nine ways:

Enhance the Transfer of Technical Information
Increase Technical Information
Improve the Patent System
Clarify Antitrust Policy
Foster the Development of Smaller Innovative Firms
Improve Federal Procurement
Improve our Regulatory System
Facilitate Labor Management Adjustment to Innovation
Maintain a Supportive Attitude toward Innovation

These recommendations are not really new; in fact, most were made originally in the Charpie report and by others since. But they are considered by many to be a useful first step in adapting public policy to our innovation problems.

Most of the studies of innovation to date focus on problems at the entrepreneurial end of the spectrum and deal only briefly, if at all, with the inventive or creative end. The suggestions made are concerned primarily with inducing industry to become more supportive of university research -- it is at best an issue controversial and difficult to rationalize.

As so much attention has been focused on our entrepreneurial concerns, I would like to address our innovative and creative capabilities, and the difficulties we have at this very important end of the innovation spectrum. Almost everyone continues to assume that we have maintained a constant flow of bright new concepts and new technology, and that our problem lies in our inability to capitalize on them because of crippling laws and an unfriendly government-industry relationship. But many today are questioning our technological lead, and they feel that we may be losing some of our creative initiative. If this is so, we have a new and difficult problem. It is this aspect of the situation that I would like to examine.

First, where do most of our brilliant new inventions or concepts come from? Of course they emerge from many different sources, but most develop in organizations that support brilliantly creative people. Innovations spring from very special environments which develop their own creative motivations and challenge their participants to think daringly. These organizations can be in universities, industry or government laboratories. In universities, new ideas frequently come from research activities centered around a facility or a self-motivating group of faculty. MIT has had and still has many of these centers of creativity, like Gordon Brown's Servomechanisms Laboratory and Jerry Wiesner's Laboratories for Electronics. Warren K. Lewis' great Chemical Engineering Department of the '40s and '50s was a hotbed of new ideas and new ways to apply chemistry to the solution of problems and the creation of new capabilities. The remarkable Instrumentation Laboratories of Stark Draper, from which flowed many new inventions, including fire control and inertial guidance, is another example. Any young graduate students who became a part of that laboratory from the 1940's through the 1960's were excited and strongly motivated towards the creation of new ideas. The important aeronautical group at Caltech under Clark Milliken and Theodore von Karman generated another great outpouring of ideas and young people who, upon leaving, played a dominant role in the application of these technologies to new aircraft design. From these great teacher-scholars and their highly motivated students came a flood of new technology and creative concepts. This technology easily transferred to our expanding high-technology industry to provide the powerful innovative climate of the 1940's and '50s.

These new technologies were not coming only from university laboratories; by far the largest contribution came from industry and government research laboratories. However, these labs were populated by the emerging graduate students, who were motivated to generate new ideas and project these ideas into new products for the marketplace. Indeed, many of these students initiated small new industries and ultimately became part of the entrepreneurial activity. The great majority of technological advances came from industrial research and development groups which were supported by active and related university programs and by educated and enthusiastic graduate students. Spectacular advances in technology have sprung from industrial organizations such as Bell Labs, Exxon, RCA, DuPont, Boeing, and others. The flow of technological advances from industry has accelerated over the past decades, while the interrelationship between industry and graduate engineering education and research has deteriorated. This is now a major problem in our innovative environment.

We have seen very productive government research and development laboratories that have made, and in some cases continue to make, strong contributions to the creation of new technology and new capabilities. One of the foremost of these was the original National Advisory Committee for Aeronautics (NACA). This organization, by careful choice of people and the creation of a surprisingly creative environment, dominated aeronautical technology development for the decades before and after World War II. Here again we see the success of a research activity populated by first-class people who are equipped with superb facilities and work in a highly creative environment. Our concern today is whether these R & D organizations are being supported adequately by our universities' graduate engineering and research programs, and whether public policy can influence these organizations.

The impact of industrial and governmental research laboratories on our inventive or creative output, and how this feeds into the entrepreneurial end of the innovation spectrum, requires a study of some magnitude. My concern here is mainly with the contribution of modern university engineering education and research programs, and their capability to influence the creative thinking of young graduate students.

In a discussion of the creative environment within our engineering schools, we should first examine several factors that influence how we do business and where some of our problems lie. First of all, modern engineering interests have their own spectrum of activity. Engineering varies broadly from what we refer to as 'engineering science' at one end, to detailed hardware design and development at the other end. Many mistakes are made when the basic differences between these two ends are ignored.

Engineering science has emerged as a major focus of engineering schools and engineering research. It involves areas of classical physics now largely abandoned by top science departments, such as solid state physics, polymer chemistry, fluid mechanics, thermodynamics, materials and so on. The emergence of engineering science has dominated the growth of modern engineering schools; many now have 'engineering science' in their names, along with expanding Ph.D. programs and faculty research. Indeed, faculty appointments over the past decade have been based largely on the expansion of interest in engineering science.

The other end of the engineering research spectrum is focused more on applications and solutions to real problems. It is here that major industrial interest resides, and the recent decrease in industrial cooperation with universities is partly due to the increasing university focus on engineering science. Industry's basic concern is that a young Ph.D. student who has done research in some sophisticated area of engineering science will not, in many cases, be motivated toward the creative role expected of him or her in industry.

No matter how we engineering faculty dislike facing it, the best engineers, unlike scientists, are found primarily in industry rather than in universities. This can be measured by looking at the election to the National Academy of Sciences (NAS); some 97% of its members are from academia, while in the case of the National Academy of Engineering, 55%

are from industry, 37% from academia and 8% from government. The university faculties stack up better at the engineering science end of the spectrum and less well, of course, at the applied end. Today we are concerned about the whole spectrum of engineering initiatives, but in particular about the applied end, where concerns over loss of invention and creative innovation are the greatest.

In order to discuss these problems further, we must look at the organization of university research in recent years. Before World War II there were only a few significant graduate research activities. A few examples were MIT's Instrumentation Laboratories of Stark Draper (Sperry), the Aeroelasticity Laboratory of Manfred Raucher (Vought), and Caltech's Guggenheim Laboratories (GALCIT) under Clark Millikan and Theodore von Karman (Douglas, North American, Northrup, etc.). There were others, but they were small. These programs had good relationships with pertinent industry, and most offered the M.S. degree only; very few engineering Ph.D. programs existed at that time.

The big change in university research activity came with the advent of World War II. During the war, President Roosevelt's extremely effective science and technology advisor, Dr. Vannevar Bush, put together two operating research entities; first, the National Defense Research Committee (NDRC) and later, the Office of Scientific Research and Development (OSR&D). Through these organizations large amounts of money were fed into R & D programs for the war effort. Vannevar Bush at that time made a crucial decision that has affected university research and graduate programs ever since. He decided to house major research and development programs on university campuses, involving the faculty and graduate students, and agreed to pay the university the full indirect costs of these programs. He decided not to pull the faculty from the university and set up centralized facilities or institutes. (An exception, of course, was the Manhattan District Project.) As a result, we have seen a large expansion of research laboratories on our campuses with sponsored research focusing more and more on engineering science and the societal aspects of engineering.

The flow of dollars into these laboratories has been large, and almost all of it now comes from government sources. Industry has disappeared as a major factor in the support of university laboratories. The important byproducts of these research activities, the graduate students, have developed primary interests even more closely aligned to the engineering science end of our spectrum. They have received Ph.D.'s, joined faculties and carried their research interests even closer to the science end. Many of these students were not motivated towards the creative interests so important to industry. As a result, the close interplay between industrial researchers and university faculties dwindled away.

The shift towards engineering science is not at all a bad thing; engineering science is a crucial element of modern engineering and must continue to be supported strongly. My main concern in this paper, however, is the applied end of the spectrum, its relationship to our total innovative process, and the part in it that modern engineering education and research should play.

There are many research activities in our engineering schools that fit the definition of applied research and are of interest to modern high-technology industry. MIT has many of these, including the Laboratory for Manufacturing and Productivity, the Laboratory for Electronics, and the Gas Turbine Laboratory. There are many others, of course, outside MIT. The output from these particular research activities can be of great interest to industry, but most engineering research programs in our engineering schools today are not well synchronized with industrial interests and do not motivate students towards innovative thinking. The main purpose of these laboratories must be to attract brilliant young students and excite them with the possibilities of a highly creative career. If we don't do this, we are getting into deep trouble at the creative end of our innovative environment.

The financing of university research varies with government agencies. The National Science Foundation has always sponsored research in the engineering sciences, and recently has made organizational moves to play an even stronger role. Basic engineering science research is also sponsored by organizations such as ONR, OSR and NASA. The more applied areas of engineering research are almost universally sponsored by the operating agencies -- the Wright Field Air Force Laboratories: Flight Dynamics, Propulsion Avionics and Materials; NASA; the Department of Energy; the Department of Transportation, and so on. The magnitude of this support is very large and dwarfs the more basic program support of the NSF.

Industry support of university engineering research has been difficult to rationalize in the face of large and multiple support possibilities from government agencies. In recent years industry support has largely been in the form of fellowships, scholarships and small grants. One support technique that has found some favor, and which is in the minds of many the best possible arrangement, is the Corporate Associate Program, a *quid pro quo* agreement between industry and a university research activity. Industry pays a set fee per year and helps with the identification of research objectives. In return, it receives quick access to all research results, frequent discussions with involved faculty and staff, and early contact with the best graduate students. The fees involved can be used quite flexibly by the research group or department and can act as seed money for many undertakings. This program is an excellent way to involve industry, particularly at the applied end of the research spectrum.

Now, what is it that industry would like to see in the technical programs of our universities? First, they want to see the very brightest of our students attracted to scientific and technical fields. They would also like many of these young people to be well-motivated towards a career in the creative areas of modern industry. To accomplish this, I believe that we have to change some of those basic interests of engineering school faculties that are too strongly oriented towards engineering science. We need more engineering faculty with industrial experience.

What changes in public policy might have a significant effect on the creative end of our innovation spectrum and, in particular, how might such policies affect the university research scene? Several such policy changes are currently being suggested and studied. The first is a decision to bolster NSF support of basic engineering research, which I interpret to mean engineering science. There are also recommendations about ways to sponsor university-industry cooperative research programs. There have been suggestions to give industry tax incentives to invest more heavily in university research programs, the value of which is dubious; I would rather see *quid pro quo* programs developed that will attract industry without such inducements. I believe, also, that those changes in patent laws and other elements to encourage innovation at the entrepreneurial end will feed back to renewed interest at the graduate level. Finally, the creation of a National Engineering or Professional Foundation has been proposed. Many supporters of this concept ignore the differences between the engineering sciences and the application end of the innovation spectrum. I feel that an NEF would hurt the NSF at one end of the spectrum, as well as the interface with the basic programs in ONR, OSR, and others. At the applied end of the scale, NEF-type support would probably be inadequate. It is far better to involve the operating agencies of the government and industry in a sophisticated way. I don't believe it is politically possible to create an NEF, nor do I think it is desirable even if it were possible. A *quid pro quo* environment can be developed in a cooperative program with industry, as has been done successfully in the past.

We seem to be in increasing difficulty over these issues. We like the university-based research group with its creative faculty and top graduate students, but feel that these groups may have focused too heavily on engineering science objectives. Our engineering faculties have less and less contact with the industrial world and its major interests. All of this can be remedied, but probably not through public policy changes. It requires only a new rapprochement between our faculties and industrial research activities to insure that creative motivations flourish. Perhaps we need to insist on some industrial experience in our engineering faculties, or depend on part-time faculty appointments with industry. We must recognize that engineering science will continue to be an important focus of engineering schools, but it must not be the major focus. I would like to suggest the following:

a) We should encourage the NSF to strengthen its basic engineering research programs, centered on the important areas of engineering science. The NSF should avoid the more applied end that can be supported more strongly elsewhere.

b) Industry and university engineering research cooperation should be strengthened, and focused on the applied end of the engineering research program which is supported by the government's mission agencies. Industry should cooperate with university programs in more Corporate Associate Programs with real *quid pro quo* aspects. Their financial support for fellowships is, of course, of great value.

c) As a large concentration of creative engineering talent is in industry, shouldn't we seek out better arrangements for setting up multiple faculty appointments between universities and industry? A total engineering faculty with no industrial experience makes little sense today.

d) We should take another look at faculty consulting. A consulting day for engineering faculty was established to insure a feedback of industrial concerns to the university. In many cases, this has been misused by faculty taking their "day" and teaching classes in industrial facilities. This is really moonlighting, not consulting.

e) Should we promote a D.Eng. degree with different requirements -- or should we eliminate the Ph.D. requirement for all faculty of the engineering school and permit, in some cases, substitution of an equivalent in industrial experience? Perhaps we should reestablish the engineering degree.

I don't believe that public policy changes will have significant effects on the creative or inventive end of the spectrum for innovation. We must refocus the attention of our faculties, and bring them into closer contact with the world of technological advance. A lot of this can be done without much government help.

In summary, a brief review of my remarks. I have identified innovation as a broad spectrum of activity that extends from an inventive or creative end to a product development or entrepreneurial end. I pointed out that many studies have been made, focused mainly on an apparent decline in our world trade position -- the bottom line of the entrepreneurial end of the spectrum. The results of these studies, until recently, have been effectively none. Our continued decline in economic vitality has attracted the attention of the President and Congress; we have seen stated initiatives come from the White House, and many bills before Congress dealing with different aspects of the innovation process. The time has come to identify important goals clearly, and lay on a program of advocacy to see that results are forthcoming. From now on, we need more advocacy and less study.

The inventive end of the innovation spectrum has been studied less than the development end, and it is not clear that changes in public policy are required to improve this area. We generate inventions and new capabilities in productive laboratories located in university, industry and government laboratories. It is essential that these organizations contain the most creative people in a proper environment with proper facilities. The university-based research entity in which highly creative faculty combined with the top graduate students generate an outpouring of new ideas is biased today by its major support from government agencies and the slow loss of interest from industry. We must re-interest industrial research units, insure that a viable *quid pro quo* is established -- make better use of part-time industrial appointments -- and expand our contacts between industrial research units and the university faculty. If we can do this well, I don't believe that we need significant change in public policy as a remedy.

BIOGRAPHICAL NOTE

Dr. Courtland D. Perkins was graduated from Swarthmore College in 1935 and received his M.S. degree from MIT in 1941. He has received honorary D.Eng. degrees from Lehigh University, Rensselaer Polytechnic Institute and Swarthmore College. During World War II, he headed the Stability and Control unit of the Aircraft Laboratory, U.S. Army Air Corps, at Wright Field. He was active in improving flight test and flight research operations within the armed forces, and had a hand in the creation of the first Air Force Test Pilot School. After the war, Dr. Perkins co-authored the fundamental book *Airplane Performance, Stability and Control.*

Dr. Perkins has been a professor on the Princeton faculty since 1947. He has served as chairman of the Aeronautical Engineering Department, chairman of the Department of Aerospace and Mechanical Science, and associate dean of the School of Engineering and Applied Science.

Dr. Perkins served the Department of Defense during 1956-57 as Chief Scientist of the USAF, and during 1960-61 as Assistant Secretary of the USAF for Research and Development. A member of the USAF Scientific Advisory Board since 1946, he served as its chairman from 1969 to 1972 and from 1977 to 1978, and as senior scientist of the USAF-SAB.

In 1963, Dr. Perkins was elected Chairman of the Advisory Group for Aeronautical Research and Development (NATO) and served in this capacity until 1967. He has been advisor to and a member of numerous national science and defense boards and committees. Dr. Perkins was President of the American Institute of Aeronautics and Astronautics in [illegible] He has served on the Board of Directors of Fairchild Industries Corporation, Am[illegible] Airlines, Inc., the MITRE Corporation, the Keuffel & Esser Co., and the C. S. Draper Laboratories.

In 1975, Perkins was elected to the Presidency of the National Academy of Engineering, and was reelected in 1978. He is a member of several professional and honorary societies.

The Role of Government as Viewed from the Private Sector

Dr. Robert Bromberg
Vice President, TRW, Inc.

In our society industry produces and markets items and services, the sales of which are profitable. Government sets and enforces the rules for transaction. Colleges and universities supply well-trained people and provide the scientific underpinnings of technology to industry.

Industry's view of U.S. innovation and productivity is as follows: 1) innovation thrives in a free and competitive environment; 2) where government funding is essential, stability of that funding is of great importance; 3) it is critical that the innovation environment be improved in terms of equitable tax treatment, encouragement of capital formation and a better risk/return ratio; 4) the regulation process should be more sensibly focused and made consistent with current realities; 5) the interpretations of patent laws should be made more consistent among government agencies.

The journey from idea to marketable product or service is long and tortuous and risky, yet industry needs a continuous infusion of new technologies. Industry is often the source of new ideas for development. Cooperative research programs will not generate many new products or services, but will affect the entire innovation-development process. Appropriate areas for cooperative research are materials, manufacturing processes and design processes -- areas of common interest that do not present many proprietary problems.

Government's roles in cooperative research ventures include providing funds and easing legal restraints on cooperation. Fundamentally, government creates a framework for healthy innovation and development.

In discussing the role of government from the private sector's viewpoint, one must address the government's role in the total innovative process and in cooperative research in particular. I would like to go over the basic roles of the various participants in the innovative process, suggest areas appropriate for cooperative research, and discuss some of the specifics relating to government's role.

The Basic Roles of Industry, Government and Universities

In our society, the private sector (industry) produces and brings to market items and services whose sales it deems profitable. The government sets the framework for transaction by defining and enforcing the rules of the game. (There are, of course, instances where the government is the purchaser of products or services, as in the defense industry). The primary contribution of colleges and universities is in supplying the well-trained people and the scientific underpinnings of technology to industry.

The Innovative Process

Innovation thrives best in a free environment with opportunities for reasonably profitable exploitation. That environment must be truly competitive; it is not helpful if government on the one hand stifles competition, as it does, for example, in not honoring proprietary positions, and on the other hand frowns upon "too much" success, fearing the emergence of monopolies. The financial environment also influences innovation. There is a need for more equitable tax treatment to encourage capital formation and to improve the risk-return ratio for those engaged in entrepreneurial activity. Most of the people in industry, government, and the general public believe that regulations are necessary, but that the regulatory process must be more sensibly focused and more consistent with current realities.

By and large, the patent policy in the United States has served innovation reasonably well. Difficulties arise when we deal with several governmental agencies with varying sets of rules, which are codified by administrative decision as often as mandated by law. Further problems occur because technology changes more rapidly than do patent laws and their interpretation by administrators. The patent rules and interpretations relative to software are a case in point. Patents are still tied to physical embodiments of things, and when a crucial invention relates to something like software in a computer, where the distinction between software and hardware is vague, difficulties emerge. We are confronted with a situation where people contrive to turn software into hardware implementation, when a sounder solution might be an adjustment in the patent system itself.

There is an old saying that "necessity is the mother of invention;" but a need is not a market. The journey from idea to invention to development to marketable product or service is long, with many convolutions and internal loops. Most inventions do not survive the trip. Yet industry must have a continual infusion of new ideas and inventions. Industry itself is probably the best source of new product ideas, but it is not always the best source of the necessary underlying technology. The strength of industry is in relating existing ideas and innovations to the needs of the marketplace.

Probably very few marketable products or services will result from cooperative research programs; more importantly, these programs will affect the entire innovation-development process. For example, many studies have tried to identify the connection between independent research and development (IR&D) as conducted by government contractors, and the tangible results it produces for the government. It is difficult to point to a one-to-one connection, but few doubt that the connection is there. If we remove the independent research and development, the innovative climate will suffer, and fewer new products and processes will result.

Areas for Cooperative Research

Appropriate subjects for cooperative research will vary for different companies according to the size and type of the institution, but the subjects are quite few in number. Generally, areas like materials, materials processing, manufacturing, manufacturing processes and the design process are best suited to cooperative research ventures. The polymer program at MIT, the manufacturing programs around the country, and the silicon structures program at Caltech all fit into this family.

There is a new surge of interest in manufacturing and manufacturing processes as subjects for university study. These studies interact with fundamental work in materials and materials processing. Much of this is not basic research, but it is nevertheless fundamental to the success of engineering enterprise in the United States.

Design is one of the essential features of several of the existing cooperative research programs. The program at Caltech has at its base the better design of a computer chip, and focuses on chip architecture, which is also design. Design is different from the kind of engineering taught in the universities, where the primary emphasis is on analysis. Analysis is easier, more straightforward, and appeals to academicians; it also appeals, unfortunately, to a large percentage of the brighter people in industry. Very few of the best people want to get involved in the morass of designing and developing things. It is cleaner and perhaps more fun to do analytical work, but ultimately, engineering is design, and we must improve our design capabilities in this country if we are to remain competitive internationally. The Japanese, in contrast, have adopted our technology and have often incorporated it into better designs than the originals. For example, they did not start out with the knowledge to design lenses, or the technology of making glass; they did not originate planar integrated circuits and knew little about photographic film -- but they learned quickly. The Japanese absorbed the knowledge, studied the marketplace, and worked backwards, so to speak. They now dominate the camera market. Ultimately, if companies are to be successful, they must study the market and work backwards, adapting and developing in response to the market.

Japan, and a few other countries, are not just export-oriented but processor-oriented. Having few natural resources other than their population, the Japanese buy all the materials that they work with. Their business is to buy, process and sell; most of the basic technology that they use was developed here or in Europe, and the success of their system has been demonstrated.

The Role of Government

One of the most serious issues we face is that of government funding for private sector technological development, development of general benefit to the entire economy and not for direct purchase by the government. "How can the government justify helping General Motors to build a better engine?" society asks, public perception being that GM has all the resources it needs. This attitude affects all of industry. It *can* be for the public good to provide public money for what ultimately will be private exploitation, if this is done appropriately, but attitudes change slowly. Publicly supported schools that depend in large part on state legislatures for their money have encountered this suspicious attitude, since some of their funds may go towards supporting local industry. The University of California, a publicly supported institution which has played a major role in agricultural development--an excellent example of successful cooperative research--is in legal difficulties. Agricultural research was performed at the university with funding from both government and industry. Industry took the results of this research and exploited them. Now the university is accused of misusing public monies to the inappropriate benefits of private companies. Any cooperative research venture that is to be successful must anticipate and plan for such difficulties.

A lot of people in government have yet to learn that profit is a necessity for the existence of business, and a welcome necessity. Government can work with industry and universities to find better ways to solve problems of mutual interest under existing law, without any new legislation. The seeding role in starting new programs is surely an important one; the programs involving the NSF are good examples. Every new problem we encounter does not require a new law; the industry recognizes the need for regulation, but it must be appropriate.

We all have the word now that the competition that we really need to worry about is not internal but external. Today's world is far different from the world before World War II; our competition is international and affects the domestic economy. If we do not make cars for American use in the U.S., for example, we have immediate problems; and the same is true for televisions and consumer electronics and cameras and machine tools and so on. We must become more competitive; the best defense, as it is so often, is a better offense.

A successful example of cooperative research may be found in the agricultural industry, which has perhaps the greatest breadth and depth of cooperative effort among universities, government and industry of any industrial segment in the U.S. This cooperation began with the establishment of the land grant colleges, the agricultural experiment stations, and the departments and colleges of agriculture and agricultural engineering. Universities have received a lot of government and industry money for the development of all sorts of agricultural technology. This is a major element in the green revolution of the last hundred years in the United States, and has enabled us to feed not only ourselves but a good portion of the rest of the world while using the smallest fraction of our people for agriculture of any society in history. This success is a result of work performed in universities and paid for by governments (often state governments) and by companies, in areas like plant genetics, seeding, irrigation, harvesting, and food processing.

Cooperative research might help us in another area: the impending severe shortage in the supply of engineers. The number of university-aged people is at its peak, and will decline steadily from now on. The universities will face funding problems as a result. The population in the U.S. continues to grow, and will grow by maybe forty million people even with the birth rate below replacement level. Our need for technology is growing, not diminishing, and with it grows our need for engineers. Cooperative research can address this problem, though it may not solve it.

Fundamentally, government creates a framework for healthy innovation and development. Neither government, industry, nor the universities alone can solve our problems; a cooperative effort may be our most successful option.

BIOGRAPHICAL NOTE

Dr. Robert Bromberg is Vice President - Research and Engineering at the TRW Defense and Space Systems Group.

Dr. Bromberg has directed research in the physical and life sciences, R&D in engineering mechanics, materials and chemical engineering, development of propulsion and energy conversion systems, and development of software and information systems. He has held various technical and managerial positions in the Defense and Space Systems Group (earlier the Ramo-Wooldridge Corporation and Space Technology Laboratories).

Dr. Bromberg is a member of the National Academy of Engineering, the Scientific Research Society of America, and the American Society for Engineering Education. He is a fellow of the American Institute of Aeronautics and Astronautics, chairman of the University of California's Engineering Advisory Council, and was named UCLA's "Engineering Alumnus of the Year" in 1969. He has been awarded patents in the fields of energy conversion, heat transfer and instrumentation, and has published numerous technical papers.

Dr. Bromberg received his B.S. and M.S. degrees in mechanical engineering from the University of California, Berkeley and his Ph.D. in engineering from the University of California, Los Angeles. Before joining TRW, he was an Associate Professor of Engineering and the Assistant Director of UCLA's Institute of Industrial Cooperation.

Questions
(Dr. Perkins and Dr. Bromberg)

Mason Somerville: We are in the applied research business, and one of the arguments that we run into continually among our industrial peers is that it is not appropriate for a university to be in the applied research business. Could you respond to that kind of criticism?

Robert Bromberg: My answer will not be very satisfying: it all depends on what you work on. I think that universities can engage in research that is oriented a little more towards the fundamental underpinnings. I think that if you start designing products you are doing the wrong thing. Yet there are some beautiful examples of universities designing products which were good things at the time, so it does all depend on the 'individual circumstances.

Frank Crane: You speak of this shortage of engineers -- can we do something to direct the students towards the more technical fields? Are there not more students going into the social sciences than the technical sciences?

Courtland D. Perkins: Actually, the trend of late is very much in favor of engineering schools and engineering education. Seven or eight years ago the point that you are making would have been very valid, but since then there has been an increase in undergraduate engineering by about 100,000. It is now up around 290,000. Here at MIT the undergraduate body has more than doubled in that time, while keeping the total enrollment constant. So I think that the trend today really is towards engineering. If you look at the past, we have had a tendency to peak out about every ten years. On that basis, we would say that we are peaking out now and about to drop. I do not think anybody really knows what is going to happen. My own view is that the pressures are so great for technical people that enrollment will stay up. Students are pretty perceptive.

Nazir Bhagat: You mentioned that universities are ultimately funded on the basis of head count. Well, industry could plan and endow more engineering chairs and student aid in the areas in which they foresee a shortage of people, which I agree is coming.

Dr. Bromberg: I hope that I did not convey the idea that there is nothing that we can do about it. What is happening in so many schools around the country is that engineering is now fully saturated. The programs are now facility-limited and staff-limited, and the schools are, so far, somewhat reluctant to make the shift in resources away from the nontechnical areas to the technical areas. I think that, eventually, the problem will probably get solved by the pressure of the students.

Legal Aspects of Cooperative Research

Mr. Ky P. Ewing
Deputy Assistant Attorney General,
Department of Justice

Innovation covers a spectrum which includes the most basic research into fundamental principles at one end, and detailed product commercialization at the other. Our economy is organized on the principle of competition between independent firms, with antitrust laws designed to insure the functioning of the competitive process free of unnecessary artificial restraints. Innovation is as important to the competitive process as competition is to the economy, and is both an objective of competition and a means of competing.

The antitrust laws do not prohibit all joint activity. The questions central to an antitrust analysis of whether joint activity is permissible are also the questions appropriate from an innovation perspective to determine the desirability of joint activity (as opposed to independent activity). Some of these questions are: Would the activity be undertaken separately by individual firms? Is the joint activity broad or narrow in scope and time? Do aspects of the joint venture limit continued independent activity? Does the venture include all or only part of the members of an industry? Will the research results be disclosed for use by others? Are the participants in the joint venture competitors? Are they large or small? How concentrated is the industry? Will the joint venture, if successful, enhance or impede the competitive process' achievement of consumer welfare goals?

There are several sources to help corporate managers apply antitrust principles in deciding whether to participate in joint activities. These include corporate legal advice, the Justice Department's Business Review Procedures *and* Guide to International Operations, *and the guide on joint research ventures.*

Holding this Conference in Massachusetts is particularly appropriate, for here nearly 340 years ago, in December, 1641, the men of property of the Massachusetts Bay Colony produced the first code of laws compiled in this country. In ninety-eight articles, the Massachusetts General Court set out its famous "Body of Liberties." Viewed through our eyes, they are a marvelous amalgam of the Ten Commandments, detailed rules of court pleading and some extraordinarily shrewd observations about how the people of the Colony should organize themselves in economic matters to attain the common good. I call particular attention to Article Nine of the Body of Liberties:

> "No monopolies shall be granted or allowed amongst us, but of such new Inventions that are profitable to the Countrie, and that for a short time."

Without stretching the historical significance of Article Nine too far, please consider several aspects of it. First, in an age when the rest of the world was commonly granting monopolies as a way of organizing business operations, the people of this Colony refused to do so. Second, they provided that no monopolies would be "allowed amongst us." Third, they did want new inventions that were profitable for the country, and provided an incentive to get them in a rudimentary patent system, but the patent grant was to be "for a short time." The first patent under Article Nine was not granted until 1646 -- to Joseph Jenks for a water mill engine, for a term of 14 years.

From those early days, this nation's history is filled with a rich tradition of industrial innovation. It bears repeating that we are still the world's leader in developing new products, new processes and new technologies and in achieving their wide dissemination and use. Historically we have done this, and I believe we will continue to do this, with an economic system organized on the basis of free and competitive enterprise.

With threads going back at least to 1641, we have recognized that the incentives to innovate implicit in a competitive economy can be augmented by a patent system bottomed on disclosure of the invention in exchange for a right to exclude others from practicing it for a limited period of time. In this century we have seen, in addition, the funding and other support of research and development efforts by the Federal Government, with their antecedents in the Land Grant Colleges and agricultural research efforts stemming from the 1860's.

As we move into the 1980's and beyond, we must recognize, as President Carter did in his Message to the Congress at the conclusion of the 18-month White House Domestic Policy Review of Industrial Innovation, that our trading partners "are now attempting to develop a competitive advantage through the use of industrial innovation." We need to respond to this challenge by developing and refining our own policies for fostering this nation's competitive capability and entrepreneurial spirit for the decades ahead.

Before discussing legal questions, I think it is important to refocus your attention on a central fact about innovation: innovation covers a broad spectrum of activity. "Innovation" ranges from the most basic research into fundamental principles, to the development of products embodying perhaps several new ideas, to the efforts to commercialize and put those products into the hands of consumers. The broadness of the innovation spectrum must be constantly kept in mind as we talk about what incentives are needed at any given point on the spectrum to produce the appropriate allocation of funds and talent to get the job done. What may be needed at one end of the innovation spectrum may be counterproductive at the other end.

My second major point focuses on the legal aspects of how we organize ourselves. Our antitrust laws, described by the Supreme Court as the "Magna Carta of our economic liberties," are designed to enhance competition and free the competitive process from artificial restraints. Those laws embody competition as the organizing principle of our economy.

As President Carter noted in his Message to the Congress on Innovation, "by spurring competition, antitrust policies can provide a stimulant to the development of innovations." In a competitive environment, businessmen have strong incentives to improve their products and their methods of production through investment and research-and-development activities. Companies that can "innovate" a better mousetrap to help meet the needs of their customers more effectively or more cheaply than their competitors can thereby increase their profits. If joint activity or cooperation among competitors is substituted for competition, the incentive for firms to make and commercialize innovations can be reduced or eliminated because none of the cooperating firms stand to gain or lose a competitive advantage over the others as a result of innovation. Illustrative is the agreement to pool air frame design ideas, approved by the antitrust authorities during World War II. Under it, air frame manufacturers were required to share with the others patents improving air frame design. When the War was over, groups of inventors who were outside the charmed circle were rebuffed by the manufacturers. The latter pointed out that they had no incentive to spend money for a new invention when they could get no competitive edge through its use. Inventors then led the effort which resulted in the eventual withdrawal of the Antitrust Division's approval and the institution of a civil suit looking to restoration of a greater degree of competition, partly in order to restore the incentives to innovate and partly to bring to the marketplace the results of new inventions.

That leads me to a briefly stated third central point. We must recognize that innovation is as important to the competitive process as competition is vital to our economy. Innovation is both an objective of competition and a means of competing. The relationship between innovation and free competition is illustrated by some industries in which government regulation has unnecessarily reduced the opportunities and incentives for innovation. One of the reasons the Antitrust Division has championed deregulation of the airline and other industries is that the pressure of renewed competition in deregulated industries can be expected to trigger innovative new ways to cut costs and improve service.

Of course, independent activity does not always result in the highest feasible rate of innovation. Sometimes the alternative to joint activity is less or slower innovation or even no innovation at all. Given these facts, it is important to realize that the antitrust laws do *not* prohibit all joint activity. Rules of *per se* illegality, which are applied to types of business conduct (such as price fixing) that are so likely to be anticompetitive that they are conclusively presumed to be unreasonable, are generally *not* suitable to judge the legality of joint projects. Rather, the governing legal standard for joint ventures is either (a) the Sherman Act's rule of reason, which examines all of the surrounding circumstances in order to determine whether the agreement on balance fosters or inhibits competition, or (b) the test of Section 7 of the Clayton Act which considers whether the joint activity may tend substantially to lessen competition.

If, for example, an individual firm cannot afford by itself to finance a research program on an efficient scale, competition would not be unreasonably restrained or lessened by a joint research effort with a similarly situated firm, because neither firm may be willing or able to compete on an individual basis. The basic issue in antitrust analysis of proposed joint research projects is therefore whether the particular project will produce more innovation or less.

The questions central to an antitrust analysis of joint activity are also the questions appropriate from an innovation perspective to determine whether joint activity, as opposed to independent activity, is desirable at any given point on the innovation spectrum to produce the appropriate allocation of funds and talent.

Let me discuss with you seven questions relevant from both an antitrust and innovation perspective in determining the permissibility and desirability of joint action.[1]

a) Would the activity be undertaken by individual firms acting independently?

If, for example, the costs and risk of research in relation to its potential rewards are so great that none of the participants would undertake the project individually, then the venture is likely to have the effect of increasing rather than decreasing competition. If, on the other hand, one or more of the participants actually engages in the research on an individual basis or has a real potential to do so within a reasonable period of time, the formation of a joint venture may slow the rate of technological progress in the industry. Some of the hardest questions of analysis are in dealing with these issues of potential competition.

b) Is the joint activity broad or narrow in scope and time?

The structuring of a joint venture can affect its impact on competition and on innovation. A project of small scope and short duration would be less likely to have substantial anticompetitive consequences than a broader, lengthier project. One way to structure competitive problems out of a proposed research project is to confine its scope to basic research, as opposed to research on product design or development areas.[2] In many cases, even large firms may be unable to invest in socially desirable basic research efforts on an independent basis, and some pooling may be necessary to fund the research effort adequately.

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[1] The Antitrust Division's *Antitrust Guide Concerning Research Joint Ventures* (1980) was published subsequent to the Conference. With the goal of assisting businessmen and lawyers in analyzing joint research ventures, the *Guide* has twenty-four pages of textual summary, discussion of eight hypothetical cases, and an appendix discussing the Division's analysis of twenty-one actual cases.

c) Do incidental restraints or activities of the joint venture limit or circumscribe continued independent activity?

Attention must be paid to any collateral anticompetitive restraints or activities undertaken in connection with a joint program. A joint venture that is otherwise legal may nevertheless violate the antitrust laws if it imposes unreasonable restrictions on the participants. For example, agreements by participants not to pursue independent research and development efforts that compete with a joint venture, or certain restrictions imposed on the licensing of patents or know-how resulting from the venture, may constitute unreasonable competitive restraints. Other types of activities by joint venturers, such as the sharing of confidential information about costs, prices and similar matters, could also tend to reduce or eliminate competition among them.

d) Does the joint venture include all or only part of the members of an industry?

Industrywide ventures that include all or most of the firms in the industry are more likely to have anticompetitive effects. A firm that knows its competitors are not pursuing independent research that may give them a competitive edge may relax its own efforts, acquiesce in a passive, unimaginative joint research program, and even resist or deter innovation by the joint program that would adversely affect its own operations. In short, it cannot be assumed that the bigger a venture is, the better it is.

e) Will the results (benefits) of the joint activity (research, for example) be disclosed for use by others?

It is well established that exclusion of actual or potential competitors from the opportunity to share the results of, as well as to participate in, a joint research project on a reasonable basis may be a ground for concluding that the joint project violates the antitrust laws. *Associated Press v. United States*, 326 U.S. 1, 15 (1945). Where access to a facility created by a combination among competitors becomes so necessary to effective competition in a particular market that exclusion from that facility places an enterprise at a significant competitive disadvantage, it may well be unlawful under the Sherman Act to continue the operation of the facility without providing access to all competitors who desire admission. *United*

[2] See Note, Joint Research Ventures Under the Antitrust Laws, 39 George Washington L. Rev. 1112, 1122 (1971).

States v. Terminal R. R. Ass'n of St. Louis, 224 U.S. 383 (1912). This of course does not mean that competitors must be given a free ride; access may be conditioned on payment of a fair proportion of the expenses of the project.

f) Are the participants of the joint venture competitors? --small firms? --large firms? --the dominant members of an industry? How concentrated is the industry?

The relationship between participants in a joint research venture is clearly relevant to the analysis. Ventures among firms in noncompeting industries create less antitrust concern than similar ventures among direct competitors. A venture among the smaller firms in an industry would normally be less likely to have anticompetitive effects than a joint project among the larger, dominant firms.[3] Also, where only a relatively small part of an industry is engaged in joint research, the competitive incentive to innovate exists to stimulate not only members of the joint venture but nonaffiliated firms as well.

In assessing the effects of a joint venture on competition, it is also necessary to consider the characteristics of the industry. For example, joint research ventures in highly concentrated industries may be more suspect than those in less concentrated industries because the risk of "parallel policies of mutual advantage, not competition,"[4] is especially high in these circumstances. A pattern or trend toward a network of multiple joint research ventures in an industry, each of which might be objectionable standing alone but which cumulatively restrain competition in research, can cause concern.[5]

On the other hand, the size and market share of the participants are only two of the factors which determine the antitrust consequences of a joint venture. Depending on other factors, such as the nature of the research and the likelihood that it would not otherwise be done, participation in cooperative research ventures by larger companies even in concentrated industries may sometimes be highly desirable.

g) Will the joint venture, if successful, enhance or impede the competitive process' achievement of consumer welfare goals?

To assess the legality of a joint venture in research, it is necessary to consider the characteristics of the industry, of the joint venture and of the proposed research. A type of joint venture permissible in one industry may not work elsewhere. Yet, in general, if the joint activity will have a positive effect on the overall rate of technological development, it is likely to be legal under the antitrust laws. If, on the other hand, the joint activity will impede or otherwise obstruct innovation, the antitrust laws are likely to prohibit it. If, for example, the structure of the research is such that the participants agree to utilize results only in accordance with the pace of the slowest of the participants, that clearly impedes the transfer of innovation to the marketplace, and impedes the working of the competitive process to achieve the earliest realization of consumer welfare goals.

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[3] See, e.g., Turner, Patents, Antitrust and Innovation, 28 U. Pitt. L. Rev. 151, 159 (1966).

[4] *United States v. Aluminum Co. of America* (Rome Cable), 377 U.S. 271, 280 (1964).

[5] See Pitofsky, Joint Ventures Under the Antitrust Laws: Some Reflections on the Significance of *Penn-Olin*, 82 Harv. L. Rev. 1007, 1033-1034 (1969).

A special word should be spoken on patents and "know-how." Much joint research involves the licensing or use of industrial property rights. The antitrust laws do not interfere with those rights, but do ask if restraints based on them are of reasonable scope and extent in light of the life of the rights and their scope. Thus, pooling of patents and "know-how" for use by the joint research venture is not, standing alone, illegal and can in fact usually be accomplished in conformity with the antitrust laws. Similarly, use and licensing of patents and know-how resulting from the joint venture can be accomplished effectively in conformity with the antitrust laws.

When you must decide whether to conduct research independently or with others, the questions I have suggested should provide a beginning for your analysis. Of course, you will want to consult corporate counsel. Do not, however, be put off by counsel's necessarily cautionary words. It is the ultimate analysis that counts.

If greater certainty is needed than counsel's opinion can give, then the Business Review Procedure of the Department of Justice is available to you. 28 C.F.R. § 50.6. Under that procedure, we will usually be willing to state our present enforcement intention with regard to a prospective venture, when its size, scope and duration have been defined with specificity and we have been supplied with all relevant data. The Federal Trade Commission has similar procedures.[6]

Since 1972, we have conducted twenty-four business reviews of joint ventures. We stated a present intention not to challenge nineteen of the ventures, or seventy-nine percent. Of the twenty-four, ten involved research-and-development projects, and we "cleared" eighty percent of those.

The *Antitrust Guide Concerning Research Joint Ventures* was made public in 1980. It joins the Antitrust Division's earlier *Merger Guidelines* and its *Antitrust Guide for International Operations* in helping clarify the application of the antitrust laws to business situations.

In conclusion, let me emphasize that clarifying dialogue between corporate research managers and antitrust counsel not only can help avoid legal risks, but can help guide the substantive decisions on how best to proceed in order to maximize innovation. As President Carter remarked in his Message to the Congress, "Innovation is a subtle and intricate process..." and there "must be a continuing battle to maintain the technological strength of the American economy." Let us hope we are as shrewd and wise in our time as the members of the Massachusetts Bay Colony were in theirs, 340 years ago, in choosing the appropriate means to continue the successes of the American economy.

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[6] Under 15 U.S.C. § 638 the Small Business Administration may, with the prior written consent of the Department of Justice, approve a joint research and development project between small business firms.

Questions

Dr. E. E. Magat: Can you apply your reasoning to Professor Suh's venture?

Ky P. Ewing: As you may know, I am prohibited by law from giving private advice, and can state a present enforcement intention only. But I will try to apply my reasoning to those facts about Professor Suh's venture of which I know.

In Dr. Suh's project several facts should be noted: the research on the program's scale would not have been done by individual companies; there is no constraint on the member companies conducting individual research in the same area; noncompetitors as well as some competitors are involved; there is a wide scholarly dissemination of information that is not having ancillary anticompetitive effects; and the research is on the "basic" end of the spectrum. Given these facts, on balance and under a rule of reason, I would say that the program's effect is positive on both innovation and competition. I see nothing in the venture, as I understand the facts of it, that would substantially lessen competition in polymers. Thus, applying the analysis in my remarks to the facts just stated, Dr. Suh's venture would clearly be consistent with the antitrust laws.

Let me caution, however, that any time a venture is continuing over a long period of time -- and I understand you are talking about decades in this case -- its nature may change. Thus a present enforcement intention not to sue might not be valid twenty years from now under changed circumstances.

Questioner not identified: Given what the Japanese and the Germans are up to, isn't the whole antitrust operation an anachronism? I do not see how it helps against the Japanese and the Germans.

Mr. Ewing: I just got back from Germany, where I talked with the German cartel officials. I was much amazed to discover that they have greater power to go into a corporation and demand records than we do. I also talked with

Dr. Schlieder of the EEC; he has fined companies up to $9.9 million, whereas the maximum limit for us is one million. My point is that there are antitrust laws that are enforced in Europe too, and they are pretty stringent.

I have just had visits from the Japanese antitrust authorities; they have a few rules in Japan as well. Indeed, as of last fall the Japan Fair Trade Commission put in place certain rules which will require the divestiture by some of the vertically integrated trading companies of stock in their ultimate suppliers.

These are just brief indications that some of the concepts in our antitrust rules are becoming familiar in other places in very real ways. So, I do not think that antitrust is an anachronism either in this country or abroad.

Questioner not identified: I am wondering if the antitrust concept itself is not in fact obsolete, because it comes from the time of the Jay Goulds and the Andrew Carnegies who cornered the money market. Now we simply print more money, so no one can corner the market any more.

Mr. Ewing: I hope that you are right, that no one can ever corner a market again or even attempt to do so. Then we will never have to bring a Section 2 case again!

Questioner not identified: Is there any distinction between joint ventures that are between an American firm and a foreign firm, and ventures among American firms that are undertaken to meet foreign competition?

Mr. Ewing: Theoretically, and in a practical sense as well, we are neutral on the issue of whether the participants happen to be incorporated in this country or in some other country. Realistically, when foreign-incorporated businesses are involved, one tends to look at a broader set of markets involved to evaluate the competitive or anticompetitive effects. One of the messages which I hope that the antitrust division is getting across to business is that we do realize that there are products around for which there are so-called 'world markets.' However, when we get into the details, we find that even the automobiles that are marketed abroad are different from the ones that are marketed here. When you reach the final end of the spectrum, the competition is in discrete markets. Perhaps scale economies are needed to produce a certain volume, but ultimately you have discrete national and regional markets.

We are not unaware of international competition in making the evaluations that we have to make. Perhaps we do not always come out the way you would like us to, but we are aware of the issues.

Questioner not identified: The correlation between increased competition and increased innovation that you emphasized begs a lot of questions. One important guideline in talking about the principles guiding antitrust is that, if something would be developed that would not otherwise be developed, it is okay to go ahead. Another principle is restraint by one huge economic power. Often, those two principles collide. That is, although you have greater economic power and run the risk of the concentration of economic growth, you will get something done that otherwise would not be done. Which of those principles takes precedence?

Mr. Ewing: I refuse to accept your particular phraseology of the dichotomy. First, the antitrust laws do not in and of themselves say that concentration is bad. They say that unilateral attempts to monopolize are bad. And they say that agreements in restraint of trade are bad. Clearly the concentration of an industry causes us to view the activities with a great deal more concern, but nobody has yet written the law to say that a particular level of concentration is illegal. There were some veiled references to various proposals in the remarks of other speakers this morning, but the law as it now stands certainly does not state that any particular level of concentration is illegal.

BIOGRAPHICAL NOTE

Mr. Ky P. Ewing received his B.A. from Baylor University in 1956, and his LL.B. from Harvard Law School in 1959. He was an associate in the law firm of Covington & Burling from 1959 to 1964, and from 1964 to 1977 was a partner in the firm of Prather, Seeger, Doolittle, Farmer & Ewing (general corporate practice, including antitrust, aviation regulation, environmental law and international law). Since 1978, he has served as Deputy Assistant Attorney General, Antitrust Division, Department of Justice. Mr. Ewing was admitted to the Supreme Court Bar in 1963. He is a member of the American Bar Association, the Federal Bar Association and the D.C. Bar Association. Mr. Ewing is director of the Washington Institute of Foreign Affairs.

PANEL I: Government and Universities

Participants:

Mr. Robert M. Colton, Chairman
Dr. Steward S. Flaschen
Mr. Fred L. Haynes
Dr. Herbert H. Richardson
Dr. Thomas R. Stelson
Dr. Sigvard Tomner

Mr. Robert M. Colton
Program Manager, National Science Foundation

This morning we had much of the important window dressing surrounding cooperative research, such as definitions of entrepreneurship and innovation, and expressions of interest in such research from a general standpoint. I hope that, starting with this panel and through the subsequent panels, we will get into some of the methodologies, developments, evaluations, and propositions for coming up with new programs and expanding upon the existing cooperative programs that currently concern us.

The subject of the panel, as well as that of the entire conference, is the examination of the process by which universities, industry and government can cooperate effectively in R & D technology development. The particular subject of this panel is the association between the government and universities. However, I do not think that we can avoid including industry in our discussion, since it is a major component of any cooperative research program.

There is a recurring national belief that cooperative efforts among industry, academia and government can be effective in the areas of technology and R & D. These efforts, it is further postulated, will lead ultimately to an increase in technological innovation and in the productivity growth rate in the U.S. Proposing methodologies, conducting studies and organizing structures for developing potentially successful efforts has been in vogue for decades. As mentioned by Dr. Perkins, as far back as 1945, Vannevar Bush, then director of the Office of Scientific Research and Development, suggested using the technological capability that was developed during wartime to obtain civilian benefits. He addressed two problems related to industrial innovation:

> One, what can the government do now and in the future to aid research activities by public and private organizations?
>
> Two, can effective programs be proposed for discovering and developing scientific talent in American youth so that the continuing future of scientific research in this country may be assured on a level

comparable to that of research during the war?

Dr. Perkins has described some of the developments at various universities that resulted from that effort. Twenty-seven years later, in 1972, a former President announced in his science and technology message to Congress the formation of the experimental R & D incentives and technology incentives programs. The objective of these programs was to test techniques for overcoming our lagging efforts in technological innovation. Under them, experimental methods were to be carried out through the cooperative efforts of industry, academia and the government. It sounds familiar.

Much of what this panel will present is based upon the results of those programs that were initiated seven years ago. More recently, and this has been mentioned several times, President Carter announced in his Industrial Innovation Initiatives Program a series of actions requiring the close cooperation of these same partners. This initiative was to a great degree based upon the successes of some of the incentives programs previously mentioned.

These activities covering a third of a century suggest one of two possible things: one, perhaps we have not done our job well enough and are doing the same things all over again; or (and I would rather believe this) stimulating innovation -- whether individually or cooperatively -- is a complex and continuing problem that is not subject to quick solutions. On the contrary, a long-term sustained effort is necessary, not only to develop needed new technologies and to address the problems encountered in eliciting cooperation, but to examine the attendant environmental and sociological consequences.

In this panel we have five distinguished persons of national and international renown who, as a consequence of their professional affiliations and accomplishments, can share with us the benefits of their direct experience in stimulating technological innovation. Their observations about what industry, academia and government, individually or collectively, view as factors influencing technological innovation may assist us in developing cooperative efforts having long-term stability and resulting in measurable economic benefits.

Before I introduce the panel members, I would like to suggest some specific issues to consider concerning cooperative research. For example, what is the role of government in stimulating cooperative research? Should it be passive or active? What form should it take? Should industry assume the lead in developing cooperative relationships with academia? What are the benefits of short-term versus long-term university-industry cooperation, where the former might be based on a specific project with a relatively short development period and the latter would result in a longer-term institutional arrangement?

What are the benefits of establishing a self-sustaining program which involves government only in the initial development stages, versus the establishment of a program in which longer government subsidization might continue under certain conditions? Should cooperative research centers focus on basic or applied research, or a combination of the two? Is there an optimum size for cooperative research arrangements? Are larger centers more or less likely to become self-sustaining? Would larger centers tend to deal with technologies having high societal benefits, and smaller centers tend more towards technologies that give individual company participants a greater opportunity to capture the research benefits? These and other issues are of prime importance.

BIOGRAPHICAL NOTE

Mr. Robert M. Colton received his B.S. in metallurgy from the Massachusetts Institute of Technology and an M.S. in mechanical engineering from the Chrysler Institute of Engineering. From 1956 to 1973, he was associated with the U.S. Army Materials and Mechanics Research Center in Watertown, Massachusetts where he held various supervisory positions.

From 1973 to the present, he has been associated with the National Science Foundation. Currently, he is a program manager in the Industrial Program (formerly, the Experimental R & D Incentives Program), in the Division of Intergovernmental Science and Public Technology, and is mainly concerned with the development and evaluation of experimental programs and institutions for stimulating technological innovation and university-industry coupling. He has been responsible for the establishment and development of the University-Industry Center program at the NSF.

Dr. Steward S. Flaschen
Vice President, International Telephone and Telegraph Corporation

What are some of industry's needs that government and universities can help fulfill? Here is one corporation's and one man's opinion.

The corporation that I represent is made up of over 250 distinct businesses, ranging in sales from $10 million a year to $1.5 billion a year. In the mainstream of our business, our technology is at the forefront; a necessity for competitive growth, let alone survival. Our primary technical needs do not generally lie in our mainstream technologies. Rather, our need is to be aware of and to take advantage of the breakthroughs in peripheral technology, in either new or existing technology outside the skills, expertise and experience of the people in our units and laboratories. We are well prepared, as are most U.S. businesses, to handle the evolution of the technology involved in our normal product lines and processes, but we are not well prepared to handle step function changes that could result from new technologies developed outside of our normal activities. As we well know, step function changes in marketplaces and products often come from industries outside the mainstream industry serving a particular market. There are many areas where this has occurred: the semiconductor industry, the computer industry, instant photography, frozen foods, synthetic textiles, and diesel locomotives, among others.

What actions should a concerned company take to capitalize on this outside work? I believe that universities and government can very well help us. President Carter's Industrial Innovation Initiatives are excellent. Their only major omission, I believe, is the lack of identification and proper emphasis of the impact of microprocessors on new product development, industrial productivity and costs. We would very much like to see a generic technology center structured around the role that microprocessors and software technology can have on productivity improvements and new product and productions process development. Computer-aided design and computer-aided manufacturing are key generic areas that the majority of U.S. business is simply not well aware of, and for this reason is somewhat afraid of. They need help. Any good work in this area from the university and government laboratories would be well accepted indeed.

A small problem that I have with the Industrial Innovation Initiatives is that they address the believers: the IBM's, the GE's, the TRW's, the ITT's. We are believers in the impact of new technology on our products, and do not have to be convinced. I am very concerned about the remaining ninety percent of companies, the small businesses in this nation that are not aware of the President's Industrial Innovation Initiatives. And because they do not know about the program, they won't take advantage of it.

I think that the universities do a good job teaching marketing, but they don't practice what they preach. They do not practice good marketing skills. To make our Industrial Innovation Initiatives truly successful, to reach out to the ninety percent of American industry that do not believe in university research and innovation, we have to learn how to market technology more effectively.

Let me give you an example. Five years ago ITT received a contract for fifty million dollars, a not-for-profit contract for ten years, to bring industrial technology to the agro-industry of a developing nation in Latin America. We assembled a skilled group of North American technologists, not only from our own company but from universities and consulting firms, and went down to this country and put out notices that we were there and ready to help. We expected, naively, to be inundated with requests for free support. Nothing happened. Oh, some of the big boys, the subsidiaries of Nestle and General Foods, came to see us, but we did not see the people we were trying to reach: the rural farmer, the rural co-op, rural agro-industry. Although we were trying to use proven technology to increase employment and to improve food supply and nutrition at the rural level, we soon recognized that nobody was going to approach us for this technology; we would have to go out and market it. We learned from Battelle and A. D. Little how commercial industrial research firms reach out to the users. We hired a communication skills expert and trained our technical people to make presentations to nontechnical people. We established a marketing department. We conducted seminars in the field. We identified key target companies, and marketed technology to them. As a result, we now have eighty projects going on with a wide spectrum of the agro-industry in this developing country. So, my first recommendation is that university engineering departments talk to their marketing departments and develop the ability to market their skills, to reach out to the missing ninety percent of industry who will not be involved in the President's Industrial Initiatives Program unless the universities market their skills properly.

My second recommendation is to give much more attention to planning. The great majority of R & D programs that fail are doomed to failure from the beginning. As scientists and engineers, we have a tendency to let our enthusiasm carry us forward, to rush ahead into exciting new technical frontiers. We will devote ten man-years to the engineering program while giving one-tenth of a man-year to the planning process; a sure formula for fiscal disappointment. Our problem in government-industry-university relationships is as much a problem of planning as it is a problem in technology. There are three key elements, I believe, in planning and communicating a successful technical relations program.

As you might expect, two of the key elements are people. The first is an experienced program manager on the university side. The second is the company coupling agent, the gatekeeper if you will. The third key element is the assignment of a critical mass of resources to the program.

I would say that Nam Suh is an example of an outstanding program manager. He is a man with the ability to communicate both with the user community, industry, and with his government and university peers. We made a very special attempt in our company to identify a coupling agent who could interface with Nam Suh's program and also be accepted by our producing units. It is no small job. These are very rare people, but unless you identify them as key program individuals, your program will falter as a result.

So I recommend that far more attention be paid to the planning process and to the identification of skilled people at the universities and at the industry liaison level. I am not overly concerned about the resource issue, because if you give these people seed money they will find ways of making things happen.

My third recommendation, however, does involve cost; I do not want to dismiss the cost problem that easily. Engineering and economics are thought of as distinct disciplines. In reality they are inseparable. Funding R & D projects is not a problem in our corporation. A far greater problem is financing the development of new products and processes that make our existing equipment, plant or tooling obsolete. I think that most people from industry will appreciate this problem in a period of high inflation, with the cost of money running at fourteen to sixteen percent. The difficulty of getting capital for new programs involving high risk is very great. Indeed, in many cases you are betting your job, if not your company, on the outcome.

I suggest that we concern ourselves with identifying ways to help reduce the capital risk in bringing an invention from the laboratory to the production line. An excellent example of this can be found in the Department of Defense, which has a production development and demonstration program to help private industry serving the Department of Defense to take on high-risk, new technology production. This is an excellent model for the government to use in following up its generic technology programs and its initiatives for industry and university cooperative programs.

I am encouraged, even optimistic, that our interaction problems can be solved, because we have already done so in the United States. My model is the U.S. Agricultural Research Program. The government funding of this program has been the most successful funding of research anywhere in the world. The agricultural universities, the Department of Agriculture Cooperative Research, the university extension system, and the county agent system working with the farmer and agro-industry have given this country the highest agricultural productivity in the world. I think that it is a challenge for the rest of us in science and industry to match that which the government agriculture policy has shown can be done. We ought to be able to do it. If we do not, it is because we, the responsible people in this room, have failed to be responsible.

BIOGRAPHICAL NOTE

Dr. Steward S. Flaschen is vice president and deputy technical director of the International Telephone and Telegraph Company. In this position, he is responsible for the development of new products and technology transfer to approximately 200 worldwide ITT companies in the fields of industrial, automotive, electronic and consumer products, and natural resources.

Following service as a midshipman in the U.S.N.R. Air Corps from 1944 to 1946, Dr. Flaschen received a B.S. in chemistry from the University of Illinois in 1947, an M.S. in chemistry from Miami University in 1948 and a Ph.D. in geochemistry from Pennsylvania State University in 1952.

He has served as vice president for Research and Development of the Motorola Semiconductor Division and has been a member of the research staff of the Bell Telephone Laboratories.

Mr. Fred L. Haynes
Director, Cooperative Generic Technology Program, National Bureau of Standards

I'd like to tell you a little bit about our Cooperative Generic Technology Program. I hope that these comments will get the discussion flowing later on, because what I am going to describe is still in the planning stages. The program will receive its funding in fiscal 1981, though a good deal of planning work has already been done. We envision our Cooperative Generic Technology Program as a decentralized structure. It will not be industry specific, but will instead be oriented to specific industrial generic technology needs. As a matter of fact, the President's program announced on October 21, 1979 referred, among other things, to the Generic Technology Centers. A White House fact sheet described them quite well, and I will quote from it briefly:

The President believes "that there is a federal role in the development of generic technology centers; that is, technologies that underlie industrial sectors. Examples include welding, joining, robotics, automated assembly." I would like to add computer-aided design and manufacturing to this list, as well as artificial intelligence and some of the areas of semiconductor technology. It also includes corrosion prevention and control, nondestructive testing and performance monitoring, and tribology, the science of lubricants, friction and wear. Because the benefit from advances in generic technology to any one firm or even one industrial sector may be small, there is less investment in the development of the generic technologies than would be justified by the overall, long-term benefits that might flow from these activities. The President has called for the establishment of nonprofit centers at universities or other private sites to develop and transfer generic technologies. Each of these centers will be targeted on a technology that is involved in the processes of several industrial sectors, and has a potential for significant upgrading. It would not supplant efforts in the private sector that are designed for specific product development. Each center will be jointly financed by industry and government, with the government share dropping to somewhere in the vicinity of twenty percent or less in the center's fifth year of operation. A minimum of three centers will be established in FY81 at a cost of about $5.2 million. At least three centers will be sponsored by the Department of Commerce, and one by the National Science Foundation. In the future, and this is key, the size of the program will depend on the proposals received and the experiences gained in our initial effort. I might add that, with respect to the generic technology centers, the role of government could be described as primarily arrangement-making and providing seed money and project money. The role of execution is primarily that of the private sector.

I would like to describe the probable sequence of events that would establish a cooperative generic technology center, as we understand it today. We would first have to assume that a group of firms representing the users, the manufacturers and the suppliers recognizes urgent, common, technical barriers which are beyond the capabilities of the individual firms to address. Furthermore, the firms must be willing to cooperate in the solution of the generic problems and foresee a high probability of success in working together. The Department of Commerce or the National Science Foundation would review the situation and determine that the public has a significant interest in the outcome. The sponsoring firm would then select an organization, such as a university or private laboratory, to become the focal point for a nonprofit cooperation known as a cooperative generic technology center. I want to emphasize that this is a private sector sponsored and funded organization, run just like any other business, and that the government's role is in creating the environment within which this can happen. The government would then fund the start-up operation of the center by providing seed money and individual project money for those projects in the research agenda clearly beyond the collective capabilities of the member firms. The Department of Commerce would either fund those projects or broker them across the government spectrum with other appropriate agencies.

In essence, the program is an opportunity for industry to get together to do its own generic research with some assistance and seed money from the government. It is really as simple as that.

To review, in establishing one of these centers, we expect that the center will generally:

> One, *identify with a specific field*, and have an in-house capability for research and development, so that the growth in expertise and knowledge would be cumulative.

Two, the center would formalize industry ties so that the work carried out would be in response to a spectrum of generic needs. It would build confidence in the transfer of technology so that the results could be put to use as quickly as possible. It would provide educational and technical services to industry in order to build a lasting relationship.

What we conceive to be the basic functions of the Cooperative Generic Technology Center are the result of studying some 140 cooperative activities throughout the world, and of personal visits by my staff and myself to over sixty facilities. Let me go over some of these functions as we see them.

Clearly, it is most important that joint government and industry funding be involved -- government funding in seeding the center, industry money in sustaining it. We have talked about developing generic technology that is of interest to the entire grouping of industries and beyond the capability of any single firm. But we recognize that, on balance, such research is not likely to produce a profit for anybody in particular and that these centers, in order to be self-sustaining, have to offer some things of immediate use to the private sector sponsors.

Another function of the center is consulting and technical assistance. We feel that this is absolutely necessary to get the technology out into the industrial sector at a rapid rate, not only to the sponsors of the research agenda, but also to those who are not sponsoring, on a fee basis. It is important to remember that because firms are getting together to work on those generic technologies that no individual firm could work on alone, the centers do not directly compete with the private sector.

Information services are of extreme importance to the private sector. Using our information-gathering facilities and the information that the center will collect, we would like to see the production of information concerning the technologies that the center is most competent in, and the diffusion of that information throughout the industrial base to small, medium, and large firms alike.

Education and training have been talked about, but in this case we are not talking about the development of curricula, which is clearly the charter of other organizations in the United States government. We are primarily concerned with providing training activities for management and labor, so that when a new technology is introduced into the workplace it is not confounded by worker dissatisfaction. Additionally, we see that these management and information training services will involve seminars, as well as technical sessions, concerning such simple things as how to program a computer or a numerically controlled machine, or how to handle new robots.

In the centers there would be an opportunity to develop strategies. By this I mean that the sponsoring firms would be able to get together with nonsponsoring firms, and, with the view from the crow's nest, make assessments about where the technology was going and where there were generic technology voids for the future. We hope to insure that the research agendas being accomplished within the centers are, indeed, generically relevant to the problems of the industries. We also feel that there has to be a technical utilization arm to this center, the function of which is to market the new knowledge produced in the center.

Institutionalizing these functions so that they are clearly responsive to industry requires, in our experience, that the private sector sponsoring firms clearly control and manage the centers. Considerable imagination will have to be exercised, in so far as university capabilities are sought by the center sponsors. As you can sense, our relationship with a university is a derivative one. That is, we deal directly with sponsors of the generic technology centers who are then free to establish the centers wherever they feel that it is most feasible. However, since universities will often be involved, we believe that the cooperative technology program offers common and substantive ground and can help to overcome some attitudinal barriers.

For example, the cooperative and generic aspects of our program give it several characteristics which should make it attractive to universities.

First, the research is generic, not proprietary. Many companies will support the generic technology center and the results will belong to all of them. Consequently, research will not be subject to the dictates of the bottom-line management of one company alone.

Second, the nature of the research will often require new knowledge, since its purpose is to raise the level of technology in an industry. While not purely basic, generic research also will not be concentrated on the product development end of the spectrum. Rather, we see the participating industries taking generic information back to their own labs and developing their own products as the competitive marketplace dictates.

Third, this research will often concentrate on the solution of major societal and economical goals: the economic goals of increased international competitiveness, increased employment, reduction of inflation, and the enhancement of our national productivity. These are hardly narrow company interests.

Fourth, the broad educational functions of the generic technology center will be comfortable to some universities. A generic technology center must diffuse and transfer the fruits of its research, often to several user industries and numerous companies. The requirements for consulting services and training as part of the technology transfer mechanism will provide enough person-to-person exchange and educational opportunity to suit the university researcher.

The generic technology center mechanism will also help solve some institutional barriers which are common to government, industry and university cooperation.

First, as a privately managed and controlled corporation, the center will have the advantage of proximity without the disadvantage of identity of hierarchical control with the university itself. As a buffer, it can provide both responses to industry and programmatic benefits to the affiliated universities, while preserving the objectivity of the ongoing and separate university research programs.

Second, industrial management philosophy will not be as prominent in the conduct of generic technology centers as it frequently is in a direct company-university project.

Third, the generic technology center will help to underwrite the risk of some of the cooperation. This will tend to ease the occasional tensions created by the two styles.

Finally, the generic technology center mechanism will encourage and allow a range of cooperative formats including the direct procurement of services, cooperative research projects, programs and consortia and research partnerships, some of which are not currently practiced.

For these reasons, we feel that the COGENT Program can make a unique and pioneering contribution to new government-university-industry relations.

BIOGRAPHICAL NOTE

Prior to accepting the position as director of Cooperative Technology, U.S. Department of Commerce, National Bureau of Standards, Mr. Fred L. Haynes, P.E., was an assistant director in the National Productivity Group, Financial and General Management Studies Division, U.S. General Accounting Office. He was responsible for studies addressing balanced industrial productivity growth in the private sector and special studies in manufacturing science and technology (e.g., artificial intelligence, computer-aided design and manufacturing). Previous GAO responsibilities include Industrial Management Reviews of all industrially-funded government operations.

Mr. Haynes was graduated by Northeastern University with a B.S. in industrial engineering in 1960, and by American University with an M.B.A. (research and engineering management) in 1968. He has done additional graduate study at George Washington University and Fairleigh Dickinson University.

Before joining the General Accounting Office in 1972, Mr. Haynes spent six years on the Air Staff where he was Chief, Plans Section for both the USAF Management Engineering Program and the Air Force application of Defense Integrated Management Engineering System (DIMES). Prior to this, he spent several years as a research and development engineer at Headquarters Air Force Systems Command. Elsewhere, he has held industrial and research engineering positions with the Aluminum Company of America, Sylvania Electric Products, Inc., MKM Knitting Mills, U.S. Gear, Inc., Rust Craft Greeting Cards, Inc., and the Cushman Shoe Company. He completed flight training as a Naval Aviation Cadet, and was Commanding Office Headquarters and Headquarters Company 91st Engineering Battalion Combat in the Army.

Mr. Haynes is the recipient of the Army Commendation Medal, Department of the Air Force Outstanding Performance Rating and the nomination as the Outstanding Industrial Engineer in Greater Washington. In 1977, he received the GAO-Logistics and Communications Division Certificate of Merit.

Haynes is active in the American Institute of Industrial Engineers (AIIE) where he has held all elective offices at the local Chapter and Region level and is a past AIIE vice president-International Operations and member of the Board of Trustees. Additionally, he is senior member of the National Society of Professional Engineers, the American Association for the Advancement of Science, the American Society of Public Administration, the Society of Manufacturing Engineers, the Computer and Automated Systems Association, the Washington Society of Engineers, and the American Management Association. He is a member of the Order of the Engineer and is listed in *Who's Who in Engineering* and *Who's Who in Government*.

Professor Herbert H. Richardson
Head, Department of Mechanical Engineering, MIT

I would like to speak mainly from the viewpoint of the university today. We have been making a strong effort at MIT over the past several years to develop better relationships with industry, and to develop various types of cooperative research and general research in our programs aimed towards educating engineers for industry. First, I will discuss what universities presently face in trying to develop closer relations with industry. Then I would like to suggest a series of principles or considerations which I feel are important to keep in mind as we try to design more effective mechanisms for interaction. Finally, I will mention a few examples, mainly from my own experience and from the collective experience here at MIT, that illustrate several modes of cooperation.

In most engineering schools, at a time well before World War II, cooperation with industry was very common. Of course, research activities were then relatively modest. It was not at all unusual for industries or groups of industries to work very closely with university faculty, and to some extent with students, in both the educational and research programs. For example, at MIT we had a long history of cooperating with companies involved with engines and propulsion, with internal combustion engines and later with gas turbines. The major facilities were provided by industry and the support for the research was provided by a consortium of industries. The educational program during those years was characterized by a good deal of attention to practical things: practice, understanding current technologies, learning how to run experiments, and learning how to design -- often by going through case studies of a particular device's design. During wartime our experience showed that this type of education for engineers was not adequate to enable them to advance the technology in major new directions. We had physicists in charge of what should have been engineering programs during the war. That made quite an impression, so after the war there was a major overhaul of the engineering curriculum in most of the leading schools. Many of us encouraged faculty members with considerable industrial experience to retire. We brought in bright new Ph.Ds who were concerned mainly with engineering science and had, by and large, no industrial experience. This trend was reinforced by the rapid growth in federally-sponsored research, research substantially involved in industry only when government was the customer. I am thinking of the aerospace and military technology industries, and so on. The situation was aggravated during those years by industry, which very often discouraged us from trying to teach design or to prepare students through involvement with the actual engineering process.

So, we have found in recent years that many of our faculty do not understand industry. They have no experience in industry. Typically these faculty are dependent on federally-supported research with a small group of graduate students, and really have no great need to interface with industry at all. In fact, it may even be a diversion of their efforts to do so. Many of these faculty have, however, interacted with industry on a consulting basis. Often we find that these very consulting relationships tend to detract from bringing connections with industry into the student-related research and teaching, because of conflicts of interest and other problems.

The difficulties we face today in industry, in productivity, in energy, in transportation, and in many other fields are extremely important. Students, more than anyone else, are keenly aware of this; we see it in the classroom and among our graduate students. We have set an objective at MIT to change the situation. We do not want to eliminate completely the classical mode of interaction, of course, but we want a significant component of our education and research programs to relate or couple closely to industry.

But to produce this kind of change is not easy. I can vouch for that personally, and I think that many of our colleagues who have tried to do it have found the same problems. Based on our experience, I would like to suggest several considerations involved in making a change towards

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bringing the university into more cooperation with industry.

First, of course, is the availability of important and challenging problems that are appropriate for graduate and, to some extent, undergraduate and faculty research. I think that this is perhaps the easiest problem to solve. Appropriate research topics can range from basic research to actual device design, and preferably there would be some of each.

Second, we need a means of faculty education or reeducation regarding the industrial environment. We cannot find junior faculty who have been brought up through industry, or who have had contact with those faculty members who have been in industry. I exaggerate somewhat to make my point, but to a large extent it is true. We need incentives for individual faculty to shift their interest from the classical mode, and include in their lifestyles greater industry involvement. In many cases, this involves changing from a very comfortable, familiar mode to one that is quite demanding: dealing with the industrial client outside the university.

The problem also relates to the establishment of promotion criteria based on factors other than the number of papers published in the journal obscurus. This requires administrative leadership in the educational institutions, and involves financial considerations. For example, perhaps we could integrate traditional consulting into the university activities, rather than having it be a separate activity.

The university needs relative freedom to discuss results and to publish generic work. Now, this does not mean that patent protection is precluded, but the university community does require a certain amount of free collegial interchange on various issues.

We need real interchange and interaction between industry and universities. I think this implies a financial commitment and a commitment of personnel and talent on the part of the industries.

We need continuity of support. A person is not going to change his mode of operation if he has a single year commitment, and will then have to go back and reinitiate whatever he was doing in the past.

Finally, there is a real need for discretionary or seed funds to promote and support these kind of activities. For example, the MIT-Industry Polymer Processing Program started by my colleague Nam Suh had seed funds from the government to begin with. These were absolutely essential to get it started. It also required a highly dedicated champion who was willing to put a great deal of effort into it, to give up many outside contacts and textbook writing and other things that he might rather have done, in order to get the program going. In general, these programs require an enormous amount of energy from the faculty members, but the results, I think, are very rewarding.

We have been experimenting with something called the "Adopt Faculty Program," in which an industrial sponsor takes a faculty member under its wing. We have had the most success here with junior faculty members. Support will be provided by the company for the junior faculty member and at least one student. A consulting arrangement is worked out so that the faculty member will spend a fair amount of time actually interacting and understanding and contributing to the solution of the company's problems, while the company will provide relatively unrestricted support at the institute for graduate student research. The consulting, of course, raises questions of conflict of interest which must be handled very carefully, but we have had success in several instances.

The Industry Dissertation Fellowship, a very innovative experiment initiated by the International Harvester Company, was started last year with six industrial fellowships to support a student in a dissertation. Most were for doctoral work, but there were one or two fellowships awarded for work at the master's degree level. The difference in this program is that the fellowship is awarded to the student and at the student's initiative, but is given for the student and his or her supervisor. The student, the supervisor and the nature of the work proposed were the three major criteria in selection. International Harvester received about 300 very interesting proposals. Of course, this type of program alone is not enough, but if it is followed up later with a substantive interaction with the university, it is a worthwhile mechanism.

Special university laboratories can be established in specific industrial areas. One of the most successful examples I can think of is the Electric Power Systems Laboratory at MIT, which was started after a couple of faculty members spent a year with the American Electric Power Company, working with them and learning about their industrial problems. They came back and started this laboratory, which has been supported for the most part by industry money. The laboratory has undertaken successfully a large number of industrial projects, and has trained many outstanding students for the industry.

Let me mention one example which has not worked out very well, but do not interpret this as an indication that we do not want to operate in this mode at all. I am referring to direct fellowships for students from companies. Many companies these days come by and say, "I would like to give a fellowship to a student. I have $12,000." And we say, "Oh well, that would be nice," but we are not all that friendly. Often, the companies do not understand our reluctance. Fellowships are very useful if they plug into an ongoing industry program; but an isolated fellowship, although it does support a student and that is nice, probably costs the institution money. On the other hand, if the fellowship support is coupled with faculty activities and additional support is provided, a much more substantive and beneficial relation could result.

As far as the government role in all of this is concerned, there should be a range of options that the government supports, such as planning grants, seed funds, and curriculum development. In many of these industry-related programs in design, manufacturing and so forth, there is a need for new curricula, and there are no good mechanisms now to support them. So, the one point I would like to make to the government is: consider curriculum development activities as well as other support mechanisms.

BIOGRAPHICAL NOTE

Dr. Herbert H. Richardson has been head of the Department of Mechanical Engineering at the Massachusetts Institute of Technology since 1974.

Dr. Richardson was educated at Colby College in Maine and at MIT. He was elected to the honors program in mechanical engineering, and was awarded the S.B. and S.M. degrees in 1955 and the Sc.D. in 1958, all from MIT.

He joined the staff of the MIT Dynamic Analysis and Control Laboratory in 1953 as a member of the Fluid Power Control Research and Development group and conducted theoretical and hardware developments in electrohydraulic servo valves, hydraulic and pneumatic rotary motors, pneumatic depth controls for torpedoes, valve stability and combustion instability. He became a project supervisor in 1957 and subsequently conducted and directed major research programs in high-speed gear dynamics, dynamic behavior and stability of gas film bearings and rotors, pneumatic servo components and systems, and instrumentation.

In 1958, he served as a U.S. Army Ordnance Officer at the Ballistics Research Laboratory in Aberdeen, Maryland where he was responsible for the design of acceleration sensors and other instruments for nuclear blast research which were subsequently commercially produced.

Dr. Richardson returned to MIT in 1959 as an assistant professor of mechanical engineering, was promoted to associate professor in 1963 and to professor in 1968. From 1967 to 1970, he was head of the Systems and Design Division of the Mechanical Engineering Department, as well as director of the Mechanical Engineering Analog Hybrid Computer Facility. His research included the fields of system dynamics, gas bearings and fluid suspensions, fluidics, fluid power control systems and components, and he has published numerous technical articles and reports dealing with this work.

Dr. Richardson's current principal field of research is transportation with emphasis on urban and intercity ground systems. He was a principal contributor to the 1966 studies leading to the U.S. High Speed Ground Transportation Act and subsequently led research at MIT which resulted in fundamental design information for intercity and urban tracked levitated vehicles. In 1969, he initiated an interdisciplinary study at MIT of personal rapid transit for urban applications. In 1970, he was appointed first chief scientist of the U.S. Department of Transportation, a post he held until 1972.

As chief scientist, Dr. Richardson was responsible for the technical program which virtually eliminated aircraft hijacking, developed a successful federally funded program of university research and assisted in the development, review and direction of numerous programs in personal rapid transit, tracked air cushion and magnetically levitated vehicles, vehicle-guideway dynamics, improvement of the St. Lawrence Seaway, and pipeline safety.

He also contributed to the development of a program, Transportation Advanced Research Projects, to support long-range research in such intermodel fields as ride quality criteria, network control and cost reduction of guideway structures. Dr. Richardson was awarded the Secretary of Transportation's medal and award for meritorious achievement.

Upon returning to MIT in September 1972, Dr. Richardson resumed research in ground transportation, broadening his interest to include conventional rail systems and highway truck transportation as well as advanced PRT and tracked levitated vehicles. He was appointed to the steering committee of the MIT Center for Transportation Studies where he developed a core graduate subject in transportation technology.

His teaching interests at MIT in addition to transportation include design, system dynamics, automatic control, electromechanics, fluid power control and experimental engineering. He was a major contributor to the planning and development of the interdisciplinary Engineering Projects Laboratory at MIT and has been responsible for major curriculum revisions in system dynamics, control and design. He is co-author of the widely-used text, *Introduction to System Dynamics* (Addison-Wesley), which is a unified approach to the dynamic behavior of electrical, mechanical, fluid and thermal systems. In the summer of 1973, he chaired a study of the undergraduate curriculum in mechanical engineering which resulted in adoption of a new and broadened program.

Dr. Richardson is active in the American Society of Mechanical Engineers having served as Papers Review Chairman, Chairman of the Panel on Transportation, Chairman of the Executive Committee for the Automatic Control Division, and as a member of the Research Committee on Lubrication. He is currently a member of the Executive Committee, Dynamic Systems and Control Division. He has received numerous awards and honors, including the American Ordnance Association Medal, the Pi Tau Sigma Gold Medal as the outstanding mechanical engineer for the period 1959 to 1963, the 1970 Moody Award (with D. N. Wormley) for the outstanding professional paper in fluids engineering as well as the Secretary of Transportation's medal and award for meritorious achievement in 1972. He is a member of the honorary societies Tau Beta Pi and Sigma Xi and several professional societies, a fellow of the American Society of Mechanical Engineers, and is Registered Professional Engineer in Massachusetts.

Dr. Richardson has also acted as a consultant to many industrial organizations and governmental agencies in the areas of transportation, fluid bearings and suspensions, fluid power systems, instrument design, stress analysis, dynamics, and automatic control.

Dr. Thomas E. Stelson
Assistant Secretary, Department of Energy

First, I would like to put on my long-term hat, that of a university administrator and faculty member, and in this context make one point.

Georgia Tech operates a large engineering research program, the second largest in the United States. Last year, our total funding was about fifty million dollars: thirteen million came from internal institutional funds, six million from industry, and thirty-one million from government -- twenty-nine million from the Federal Government and two million from other governmental elements. This data, however, is quite misleading; of the Federal Government money, perhaps as much as eight million comes through a partnership between Georgia Tech and industry. We come to the Federal Government saying: "This is what we need for our industry work. This is how it is going to work." Georgia Tech is the contracting mechanism. So, perhaps as much as half of the research is very closely coupled to the needs of industry, even though industry funding is very much smaller than that.

I would like to put on my other hat for a minute, that of a government official, and describe the problem from that side. I work for a mission agency. We are currently in the appropriation hearing period, and in the last two weeks I have been before four Congressional Committees defending my $1.8 billion portion of the DOE budget. Probably the most complex portion, it deals with conservation and solar energy, neither of which is very well defined in anybody's mind. I have learned through experience that I can keep in mind only a few hundred program elements when I study something to make a presentation. In the budget I had to defend, 200 elements means only five-million dollar items. I have to forget about everything under five million dollars and concentrate on those 200 biggest items. When you are responding to a Congressional Committee, you cannot go back and read your notes without discrediting yourself.

600 people work for me in the DOE, out of DOE's 20,000 total employees. Of the 600, about 300 are involved in bureaucratic activities. There are about 300 involved in programming activities, and about half of those are support personnel, secretaries and so on. So there are about 150 professional program people, and the budget is $1.8 billion. The average responsibility, then, is twelve million dollars. Recently, I talked with a group from the Department of Defense. They have an upper limit of ten contracts per monitor, and would like to keep it at five. If you take twelve million dollars and you divide it by ten you get $1.2 million. So a program manager does not really want to talk to anybody unless they are interested in one million dollars or more. I get faculty members coming to my office who have great little ideas and they want $50,000. I cannot get a program manager to talk to them about $50,000. If managers had programs like that, they could not handle them working twenty-four hours a day, seven days a week.

The government, through these management constraints, is shoving management responsibilities off to other agencies -- to universities, industry, anyone who can get their act together to do a good job and relieve the government of the management burden. So I look very fondly on the possibilities of getting aggregates of strength together among universities, industry and so forth. That is going to solve one of my biggest administrative problems. The day of the one faculty member research program is, I think, almost gone -- except in the few areas of government, like the NSF, which are designed for that kind of system. But even the NSF has problems with this type of programming.

Our biggest single problem is the management weakness of universities, and the next biggest problem is the management weakness of the government. In working on these two problems, I think that we can put together good new programs.

It is safe to say, I believe, that an institution like Georgia Tech is an absolute bargain for industry, which is what we intended. The Georgia Tech program in four years grew by a factor of four. There are a lot of good mechanisms in place for this kind of program-building in a cooperative arrangement between universities, industry and the government. But in managing the fifty million dollar program at Georgia Tech, we had a total central staff of four people: myself, a colleague and two secretaries. It is very easy to overload a staff of that size. And, as you may know, most faculty would probably prefer to have no central staff, and to operate the university as a committee of the faculty. Furthermore, the taxpayers are likely to be even more negative towards administrators in a public institution than they are towards student radicals. There is not much strength in universities to react to new and complicated programming arrangements. I think that that is the biggest single problem that will be faced in building this improved partnership.

It reminds me of the story of two fellows sitting next to each other in a bar. One decided he would try to stimulate a little conversation, so he said to his neighbor, "What is the biggest problem in this country, ignorance or apathy?" And his neighbor said, "I don't know, and I don't care."

BIOGRAPHICAL NOTE

Dr. Thomas E. Stelson is the Assistant Secretary for Conservation and Solar Energy in the U.S. Department of Energy.

From 1971 to 1974, Dr. Stelson served as dean of engineering at Georgia Institute of Technology. Since 1974, Stelson has been vice president for research and professor of civil engineering at Georgia Tech. During his first year as vice president, Dr. Stelson identified promising programs for practical applications and doubled the research effort. Under his leadership, Georgia Tech became a center of excellence for information transfer of simple technologies, including various solar technologies, to underdeveloped countries and to rural areas in the U.S.

From 1952 to 1973, Dr. Stelson was on the faculty at Carnegie-Mellon University in Pittsburgh, Pennsylvania and served as head of the department of civil engineering from 1959 to 1971.

He received bachelor of science, master of science, and doctor of science degrees from Carnegie-Mellon.

Dr. Stelson is or has been a member of many national and international organizations, including the DOE Energy Research Advisory Board, the Engineers' Council for Professional Development, the American Society for Engineering Education (past president of the Southeastern Section), the Georgia Society of Professional Engineers, the American Society of Civil Engineers, the board of the Southern Solar Energy Center, the Council on Research and Graduate Study of the National Association of State Universities and Land Grant Colleges, and the board of the Council for Governmental Relations (of research universities).

He has been active in organizational and management activities in both government and business. In Pennsylvania during the late 1960's, Dr. Stelson was one of the leaders of a program to reorganize the state government. He has also started several new companies emphasizing the use of systems methods in management and engineering and has published many books and periodicals in the areas of engineering and education.

Dr. Sigvard Tomner
Director, National Swedish Board for Technical Development

The organization known as STU (National Swedish Board for Technical Development) deals with projects related to universities, cooperative research, industry, development companies and private inventors, among others. I will limit my remarks here to cooperative research. I want to point out at the beginning that we may define cooperative research a little differently from the way it has been interpreted at today's sessions. We do not expect the cooperative research program to generate innovations in the short term, but rather over a longer term. However, we agree that the activity is between industry and the university.

In Sweden, we have had this type of cooperation for quite some time. It started in 1940, when we established a research institute responsible for technical research in several areas, with separate branches to deal with the different areas. Government and industry shared the financing of this institute. By 1968, there existed eleven such institutes in Sweden. STU was founded in 1968, along with the organization of a central governmental agency, which accompanied the decision of Parliament to implement new directions for cooperative research. There was a shift of emphasis from the financing of existing institutes to the financing of research programs. I think the reason for this is obvious: it is more interesting to talk about technology areas than existing institutes.

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In some of the cooperative programs there are as many as fifty or sixty participating industries. In certain subprograms, where perhaps a more limited number of industries focus their particular interest in a narrower area, the result is a more effective channelling of energies and interest. Arrangements should be made to take into account industry's particular interests, and these should be recognized in the general agreements of the program.

Membership in our organization is voluntary, and since there is government money in the program it must be open to all firms wishing to take part. Of course, participation will cost a certain fee, but no Swedish company can be excluded. Today in 1980 we have thirty-one cooperative programs.

With respect to organizational management of the STU and a group of enterprises, let's say that the various companies find areas in which they are interested in increasing their knowledge through research. Who takes the initiative? Actually, this develops out of the communication between government and industry; it would be difficult to say that the initiative is clearly with either side. Rather, it starts with the communication process itself. Seed money is very important. In order to identify a program you need some sort of pre-studies, and the seed money for this is provided by our organization. We want to emphasize that we willingly invest seed money for investigation prior to the program. We think this contributes to the higher quality of the program. But in the main, we basically want the industrial group to feel responsible. It is their program and their needs that are reflected in the final program direction.

The responsibility of carrying through a program where an institute is involved lies with an appointed board of directors, half of whose members come from the enterprises and half from our organization. Where no new institute is involved, the program board is appointed in the same way.

In most cases it is the STU policy to encourage industry to contribute more than fifty percent of the program costs. During the last year, STU contributed twenty-five percent of the total, about fifty million Swedish kroner (approximately $10 million), towards the cost of operation of cooperative research programs, and industry would have to contribute to the overall programs something on the order of eighty million Swedish kroner. The financial participation by STU in the cooperative agreements varies from thirty to seventy percent. The basic rule is that industry should provide the major part of the financing for cooperative research. But there are areas where it may be difficult to identify research results of interest to industry. Such an area is corrosion, where the real benefit of the research activity accrues to municipal organizations or governmental organizations.

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Our primary tasks are to increase knowledge; to know more about an area and to upgrade technical standards, which includes such things as quality control methods and training. We feel that one of the very important aspects of the cooperative program is the assistance in postgraduate training of young researchers, geared to the requirements of industry. The cooperative activity serves as a point of contact between the universities and industries. It is possible to make expensive equipment, the cost of which is too high to be carried by any one individual or industry, available for a group of industries. It is equally important that the service necessary to run these instruments be provided by the cooperative program.

Another primary function is providing information, and this information should be made available to small and medium-sized firms. We feel it is very important that the competence of the people in the cooperative program should be such that they can solve very specific problems where the industry wants to place very qualified contracts. The payment for those contracts is outside of the agreement.

There are problems associated with everything. For instance, our Textile Branch Institutes are in decline. What should we do in a case like this? If you remove the institute, you could take away the possibilities of the branch finding new areas to investigate and in which to support a substantial cooperative program. In the group of companies, you have both small and large companies, and this implies very different capabilities regarding technical developments. You should be able to speak with both. And here I want to stress that in the cooperative activity you cannot expect the industries to put forward their most interesting ideas about new products. It is natural that the work in the program is on a more general, broader base, and this could lead the people working in the program to feel distanced from the product-oriented work. They might lack a sense of market-pull conditions.

It is important to maintain optimum size. A group can be too small or too large. While the opportunity to acquire expensive equipment is important, in certain instances the utilization of these instruments might be rather low and one might consider whether these expensive instruments are essential. Lack of flexibility is always a problem in a research institute. The goal of the work in the institute is not to make the institute large, but to be of significance to the surrounding industrial world. In other words, you are not necessarily successful if you create a large institute; and more important successes may be very difficult to show. Sometimes this makes it hard to maintain flexibility.

We believe that in the future we will certainly continue to use cooperative research. We want to have this policy. Perhaps we should play a role in initiating and trying to establish qualified programs. But we also want the industrial group to feel responsible, and after a couple of years or more into a program, we want industry to successively take over more and more responsibility so that we can get out. There are areas where society is particularly interested in the use of technology. There might be in such cases reason for a heavier involvement of government money.

Even in the United States, certain research indicates that increase in employment is greater with small companies than with larger companies. In other words, the dynamic smaller companies will play an important role in the future, and should be able to take part in cooperative research and the use of technology and research results. Many important results are not currently being used, and we think that cooperative research could play a role here.

I will describe briefly the situation in other countries in Europe. There was a workshop in the Netherlands in November 1979 entitled "Trends in Collective Industrial Research," which describes the European situation more extensively.

In Germany, the situation is characterized by the fact that industry owns the institutes, and the industry ownership is organized under an umbrella organization for industrial research institutes, the AIF. The funding of AIF is twenty-five percent public, which was one million deutschmarks in 1954, and in 1979, sixty-seven million DM; quite an increase.

The United Kingdom's old system started in 1917, and the policy since 1971 is called the Rothschild Principle, which is very shortly expressed as "If a piece of research is to be done, there must be a customer who is prepared to pay for it and a contractor to do it." As a matter of fact, the government contributes fifteen percent, but in a direct contract requirement, where there is work done for the money put in.

The Netherlands has one big independent organization for applied scientific research called TNO, and government contribution to the activity is rather heavy.

In France, there are few programs and the financing is done by parafiscal taxes. The industry does not choose to be a member; it must participate if it is located in certain branches. This has been criticized lately and may be changed.

BIOGRAPHICAL NOTE

Dr. Sigvard Tomner is currently Director General and Chairman of the Board of the National Swedish Board for Technical Development (STU), a governmental agency for the planning, initiation and support of technical research and development within universities and industry. He has previously held positions within the LM Ericsson Telephone Company in Sweden and the Radio Corporation of America in the United States.

DISCUSSION

Robert M. Colton: The identification of proper locations for cooperative research, from the standpoints of the university, the faculty and the possible industry participants requires some discussion, especially concerning the government role in identifying these kinds of organizations. Do I have any volunteers to attempt to answer these questions?

Sigvard Fommer: I think the government role is to provide seed money and initiate the project, and then the role should become smaller and smaller.

Steward S. Flaschen: Seeds do not grow when they are sown on concrete. I think the points that panel members made about management and selection of people are absolutely crucial for the success or failure of any program, no matter how well thought-out the technology is.

Mr. Colton: Suppose you put in the Congressional Register the following notice: "Looking for bright applicants for cooperative research programs; please send vitae to the National Science Foundation." Do you think that is an appropriate way to do it? Or maybe ITT would want to put an advertisement in the National Association of Manufacturers, or something similar.

Fred L. Haynes: I think that we have already taken the position in our cooperative generic technology programs that the responsibility for selecting the management of the centers themselves, and for selecting the competence base, is up to the private sector. In essence, they will be spending their own money and we are suggesting that they put in sufficient levels of money to get top management's attention. Put those two things together -- get their attention and the money -- and we expect that top management will make the centers successful.

Mr. Colton: How about the selection of technology? Should we resort to technology push or market pull; that is, shall we list the areas of technology that we think industry ought to get involved with, or respond to those areas that industry feels ought to be more productive and better supported by the government? Are there any comments from the audience?

From the audience, not identified: Both...

Mr. Colton: Both? What does that mean? Do we come up with the list? Do you think there is any presumption in the fact that the government comes out with a list of research areas, as opposed to, let us say, government eliciting responses from the private sector? Do you think there is a psychological difference in approach? How would you feel if someone told you that "This is what you want to do" rather than asked what you believe ought to be done? That is a rhetorical question, but any comment would be of interest.

From audience, not identified: I do not think that the problem is one of presumption in cooperative research. Rather, the chances of research area designations being valid when they come from outside the market pull are very low. Mistreatments are common in this situation. We delude ourselves into thinking that someone who is not involved in a process should tell someone inside what to do.

Mr. Colton: Then the question arises, who decides what the qualifications of validity are? Is that an industrial or a government decision?

John Thompson: In Britain, quite apart from the Research Associations that our Swedish friend was talking about, we had a more recent rush of blood to the head in what I call the "ologies." We started off with tribology, then tero-technology, and now anti-corrosion technology. In each case, we asked an august panel of expert chaps, many of whom were from industry, to deliberate on our needs in a particular "ology." They then came up with advice for the government. What happened subsequently was to some extent a function of how much money they claimed the lack of effort in the "ology" was costing the country. For example, they said that in tribology inadequate use of the oil can and associated techniques was costing Great Britain 500 million pounds per annum. No one could either prove or disprove it, so we set up two institutes for tribology.

Dr. Flaschen: I almost think the choice of which technologies to take as a first four or five in a cooperative venture is immaterial. I think the important thing is to establish the communication links between the industrial scientist and manager on one hand, and the university community on the other. Out of that communication comes the process of good planning and the process of acting, and I think that this surely is what we are trying to build up for the future.

Speaker not identified: Mr. Haynes, what is the level of funding that you anticipate the government will provide to induce companies not to go and deal directly with the university without the government being involved at all?

Mr. Haynes: We do not want to induce the industry to refrain from dealing with the university. That is not our intent. Our interest is primarily to create an environment, or a ballgame if you will, to accommodate industrial firms that wish to join together to do their own generic research agenda. When we have a clear indication of that happening, we would then be interested in providing seed funds to speed it along.

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Speaker not identified: Let me rephrase my question. What funding is the government going to provide even to deal industry into the game, so that the industry does not do the normal thing with the university, but looks to the government for guidance?

Mr. Haynes: It is difficult to answer that question because we are not asking industry to look to us for guidance. We are looking to industry for guidance. The COGENT program is designed to be responsive to industry's needs. We have no research agenda in our hip pockets. In going about getting industry's interest what we have already done is get an individual or group of individuals who are *persona grata* with the industries, and identify generic research agendas that are so compelling that the individual firms wish to cooperate together. When this is clearly demonstrated then we are interested in forming a center and moving ahead with that group, to get them to congeal and move forward faster than they would otherwise. It is a different kind of program from what this nation is used to. This is the first time that government has attempted to experiment with the private sector, and in an area where the government will not be a major marketplace for the products produced.

Speaker not identified: Have you yet chosen the four areas?

Mr. Haynes: No, there are actually fifteen candidate areas right now and we are trying to identify which have the most appropriate interest to the government and which, when you come down to the dollar signs, top management is willing to sponsor.

Speaker not identified: Could you tell us what some of these are?

Mr. Haynes: Sure, it is public knowledge. We are looking at semiconductor equipment manufacturing, composites, powder metallurgy, tribology, computer-aided design, computer-aided manufacturing, artificial intelligence, robotics, corrosion, paint, graphics, construction, food processing, food distribution, radiation processing, welding, joining, etc.

Speaker not identified: Can you explain how such an organization will differ from the existing industrial associations?

Mr. Haynes: These will probably be separate from the existing industrial organizations, though we hope that such organizations (including trade organizations) will find it attractive to participate and be sponsored as members of the board or directors of our cooperative technology centers. For the most part the associations do not possess an in-house R & D capability, nor do they possess the focused ability to spread the technologies out through their industries and other industries which may be interested. That is probably one of the main deterrents in the U.S.; although lots of money is being spent, most of our efforts are diffuse and unfocused. That is one of the things we are attempting to change with the cooperative generic technology programs, and that is one of our program's major differences. In addition, many of the existing industrial organizations have a lobbying interest. You cannot usefully mingle these two activities, at least not under our existing models.

Speaker not identified: I would like to steer the discussion away from the big issues to a very important smaller issue. The individual faculty member who might be interested in getting industrial support for some of his research now needs to find out what industrial needs are. He or she does not know how to go about doing this. He does not know how to schedule research for industry because once he ties in with an industry, he will then have to coordinate, usually with in-house programs, and his research will have to mesh with them. In my experience most faculty do not even realize that they have to develop these skills. I wonder if anyone on the panel has any suggestions about how university people might be shown first that they need to do this, and second, how it can be done.

Dr. Flaschen: How do we tap the skills of the university professors who have no industrial experience? We cannot leave them out; they are too valuable a resource. I submit that the program manager does not have to be the technical expert. The program manager at the university should be, however, someone who is credible in the university faculty and who also has industrial experience. He is the internal "gatekeeper." He is the key "interfacer" that the faculty member should work with to get that day-by-day, week-by-week identification of what his problems with industry are, and what his problems are in marketing his group's skills to industry.

Speaker not identified: Can you give some examples of this program manager?

Dr. Flaschen: Nam Suh is the perfect example. Here is a man who came out of industry and who certainly made this program, the Polymer Processing Program, succeed. It took a lot of blood, sweat and tears, but he understands how to communicate with industry. I think those skills can be used effectively at MIT to help other university professors without this background to succeed in industrially supported programs.

PANEL II: Industry and Universities

Participants:
Dr. George S. Reichenbach, Chairman
Mr. Robert D. Lauer
Dr. George E. Dieter, Jr.
Dr. James D. Bruce
Mr. Richard W. Reynolds

Dr. George S. Reichenbach
Vice President, Norton Company

I will approach the issue of university-industry interaction primarily from the perspective of the individual within an industrial organization. I invite those in the government and in the universities to follow through this train of thought as I discuss the reaction of the individual in industry, and imagine how an individual within your organization might react.

The industry class that I will discuss is very specific: reasonably big, competitive industry with significant technical products and processes. The copy machine industry fits this description. The steel industry or the machine tool, computer, photographic, abrasives or energy conversion industries -- reasonably mature and competitive industries of reasonable size -- could also be settings for the scenario I will draw.

If we look at these industries at a given point in time, say today, we will find that some sort of competitive balance exists. All the companies in the industry do not look the same, even though they all make copy machines or they all make grinding wheels. They are obviously of different sizes with different sales, growth rates and profit levels. They have different market shares, in different segments of the market, which can be apportioned according to product type or geography or some other criterion.

Why does this come about? Why don't all the companies in one industry look the same? Well, increasingly each of us in industry is trying to capitalize on our relative strengths. We are doing more analysis. We are looking at our companies and asking, "What do we have to win with in this competitive marketplace?" And a university could do the same. What does it have to win with in the university marketplace? Or what does the government organization have to win with when competing with other government organizations? We try to capitalize on our relative strengths, and these strengths can be of various types. They are relative and not absolute strengths. If you are an incompetent company, but there are no companies of any talent whatsoever in your industry, you can still make a lot of money, but don't expect this pleasant situation to last for long. We may have R & D strength. We may have a bigger laboratory than the other company, or better distribution. Perhaps we are favorably located with respect to the major markets. We may have a patent, which is a nice thing to have; or an exclusive patent which is very difficult for other firms to match. We may be big enough to have a scale advantage in manufacture. If you fall behind your competitors, even in the making of grinding wheels, you will probably lose.

More and more companies are coming to understand this, and they are explicitly trying to use it in management techniques, conducting an analysis and then building up a program based on the analysis. We talk about strategic planning by business units, and management by objectives, where everything is tied together. The business schools are pushing this approach. The Boston Consulting Group, a local organization, is making a good income training people how to do this. As a result of all this you tend to see specialization within the industry. We have companies breaking down the subsegments and finding a niche where they are comfortable. A typical niche involves taking what I call the high road, where you have a high-priced, high-performance product, always in stock and serviced well. You spend a lot of money on research and customer service and entertainment. Other companies may take the lower road; they sell the same product at a very good price, but they do not give any service. They keep the high-priced people honest. Some people have a distributor on every corner; you can buy their product no matter where you are. For example, Kodak in the yellow box is in every drugstore. Some companies concentrate on the few big users. They do not worry about having their product on every corner, but sell just to the industrial market, for example.

There are all sorts of specializations. A company or industry can perform better than the others, and it can gradually change its position, but these situations change rather slowly. Sometimes a company grows because it has a particular irresistible advantage; some companies fail because they don't compete well -- but both failure and success take time.

The managers in these companies (and here I am talking about individuals) usually are not wholly satisfied with their lot. They say, "I wish I could do things better," or "I wish I had that big research department." But they also feel that, given the external competitive scene, they are doing pretty well in their environment. They have a tough job, but are succeeding given these constraints. So there is a certain amount of self-satisfaction. This frame of mind is typical: "Given the constraints, I'm working hard, and I'm doing OK." This tends to apply to everyone in the organization, from the research man to the general manager, and everyone in between. It is a form of job security. If you think you are doing all right, and your boss thinks you are doing all right, then things are OK. But this leads to a frequently found situation, the "not invented here" syndrome. This same behavior can be seen in any group, be it a university, a sports team, or an individual company.

Now, given this environment, a cooperative research effort is proposed. It looks good on paper, but how do people in the organization view it? In many cases they see it as a threat to the established order. If they knew exactly where the research would lead, they might say, "Well, the outcome is going to be all right, so I'll go along with it." But research is hard to predict. Let me list what I call "motivators" for various organizations, and talk a little bit about them.

I put 'job security' at the top of every motivator list. I think for most people the first priority is to preserve their jobs -- not produce a return for the stockholders. If I can preserve my job and also produce return for the stockholders, I am willing to do it, but job preservation comes first. There are certain corporate controls, and I cannot go and spend money without meeting certain return-on-investment targets. But those constraints are not applied when I hire people to start a marketing program. There is a fair amount of freedom here to act without worrying about the return to the stockholders. Second to job security is the motivation to gain some relative advantage. First, I want to gain an advantage for myself; to produce a new product or meet the annual goals which I committed to my boss. I would like to see the company grow as that new product gains market share and makes me more competitive. If I am producing more products and succeeding in the marketplace, my organization gets bigger and I get promoted. And so forth down the line.

The university man has other motivations. Job security is important, but he sees basic understanding as something that is good for him to be involved in. He likes to educate students. Peer approval and the financial security of his organization are also important to him.

This is how different people react. Now, let us say we are going to put forward some extra research money. How do the industrial man and the university man react? I think if when we provide this money we simply call it "extra cooperative research money," the university man says, "That is going to help me meet most of my objectives." Extra money at a university, especially in a cooperative program, is going to advance most of these things.

The industrial researcher is not so sure that "extra research money" going into a cooperative program will advance his job security, or give him a relative advantage over his competitor. I think his initial reaction is negative. When you interject a new element into a quasi-stable competitive environment, people are usually upset about it and are not sure what will result. After a while, if they see it is inevitable, I would expect them to get cautiously involved; they will go to the meetings, but they will keep their ears open and their mouths closed. They may pick up ideas that contain some advantage for themselves or their company, but they keep their mouths closed in order not to give anything to their competitors. You will seldom see full and complete cooperation at least in the early stages. If you ask the industrial man's advice on how to direct the research work, he will tend to point it in the direction that will give relatively more advantage to his company than to another.

It is important to remember that this is the way people react. These problems are not insurmountable, but they are normal gut reactions for most people. There is no easy, stroke-the-pen way to solve them. You have to build slowly and get the confidence of all involved. These basic conflicts at the individual level in cooperative research programs cannot be avoided. So, set goals that are realistic, recognizing these basic conflicts. As was mentioned before, we should work in areas of minimum conflict, avoiding the cornerstone activities in the cooperative program.

BIOGRAPHICAL NOTE

Dr. George S. Reichenbach has been vice president and general manager, Materials Division, of the Norton Company in Worcester, Massachusetts since 1979. He received a B.M.E. from Yale University in 1951 and an M.S. and Sc.D. from MIT in 1952 and 1956, respectively. A member of the faculty at MIT until 1966, Dr. Reichenbach was a principal consultant to Norton Company from 1966 to 1969. He became the director of R & D, Grinding Wheel Division in 1969, and served as divisional vice president and general manager, Organic Products in the Division through 1974.

Dr. Reichenbach has published technical papers on grinding, lubrication, fatigue, mechanics, and has co-authored three textbooks on applied mechanics and materials behavior. He received the Alfred Noble Prize of Joint Engineering in 1961, and the Yale

Engineering Association Award for Achievement in Basic and Applied Science in 1962. Dr. Reichenbach is a member of the American Society of Mechanical Engineers. He is a member of the Industrial Advisory Board - Laboratory for Manufacturing and Productivity at MIT. He is a former member of the Plans and Policies Committee, Industrial Research Institute and the R & D Council, American Management Association.

Mr. Robert D. Lauer
Director, Industrial Program, National Science Foundation

I would like to describe our industrial program at the National Science Foundation, and present some of our findings to date. Historically, there are four separate elements to the program: small business innovation research, innovation centers, technology innovation projects, and university-industry cooperative research centers.

The industrial program experiments with small business are designed to increase R & D expenditures in innovative projects in small business. A three-phase solicitation is used, with engineering and applied science National Science Foundation fundings for the first two phases. The last phase requires third-party venture capital to develop the innovative applied research deemed feasible in Phase I and performed at Phase II.

Phase I awards about $25,000 and runs about six months. Only those who had Phase I proposals or awards may submit proposals for Phase II. We have had three solicitations to date and have received 329 proposals on the first, 408 proposals on the second, and 530 proposals on the third. We are currently going through the evaluations for the third solicitation. On the first we made forty-two Phase I awards, and about thirty Phase II awards. On the second solicitation we made fifty-six awards, and are currently in the process of evaluating its second phase.

The second element of the program is innovation centers, which examine the development of entrepreneurial and innovation skills and idea evaluation. There are currently four of these centers: at MIT, Oregon, Carnegie-Mellon, and the University of Utah. Many new companies have evolved out of these centers and many jobs have been created. The Oregon center has evaluated nearly 10,000 ideas for small independent inventors, for a fee of about one hundred dollars each.

The third category is technology innovation projects. These experiments deal with mechanisms to foster university-industry cooperative research on a single project which will accelerate university-based research results into industrial applications. These projects all have their origin in research previously funded by the NSF. The Westinghouse project is perhaps the best known example of this class of experiments. It draws upon seven previous experiments in programmable automation for batch manufacturing, ranging from vision systems to parts feeders. At the Westinghouse research center in Pittsburgh, the research results will be used to do a proof-of-concept experiment in the batch manufacture of small electric motors. The experiment was considered to be too high-risk for any one company to undertake and benefit from alone.

The fourth and last category of experiments is the university-industry cooperative research center experiments. In these centers the NSF provides the seed money to get a center started, and industry picks up an increasing amount of the support until the center is completely self-supporting on industry funds alone. The Polymer Processing Center here at MIT, run by Nam Suh, is the most successful example we have to date. Another example is the university-industry cooperative research center in interactive computer graphics and computer-aided design at Rensselaer Polytechnical Institute. The computer-aided design center focuses on industry's longer-range R & D needs in interactive computer graphics, its use in computer-aided design and its interface with computer-aided manufacturing. The goal of the center is to facilitate the development of computer-aided design technology and encourage its acceptance by industry. It also provides operation and design experiments in computer graphics to students participating in the center's activities. Computer-aided design and computer-aided manufacturing offer important productivity gains for U.S. industry. The center currently has eight industrial members: Prime Computer, Imlac, Grumman, GE, AMP, Bethlehem Steel, Lockheed, and IBM.

I would like to describe some of our findings. Industrial program experiments have as their goals the identification of barriers to university-industry cooperative research, and the understanding and measurement of the effects of key variables in successful university-industry couplings. This is a complex task. Moreover, the key variables themselves are likely to be of different importance in university-industry center couplings and in the technology innovations projects. Therefore, another goal is to compare differences within key variables underlying successful university-industry centers, and single out projects to determine the optimal coupling arrangements in each case.

Several barriers to university-industry cooperative research have been identified to date. There are at least five major operating issues where university and industry responses are significantly different. Successful university-industry couplings must overcome these barriers. The following are the key variables that have been examined to date in seeking to work out resolutions of these fundamental areas where interests conflict.

The first is *leadership*, the manner in which the direction of the center is achieved. Alternative modes have been structured in our experiments.

The second is *university compatibility*, the term used to denote the degree to which university researchers respond to opportunities for cooperative work with industrial researchers. A number of institutional factors affect this response.

The third is *industrial characteristics*. These identify the salient features of companies and industries most frequently involved in university-industry cooperative research. Interrelated economic and technological considerations are the dominant factors here.

The industrial program is examining the way these experimental variables interact to determine coupling outcomes. It is essential to understand this if we are to strengthen university-industry linkages in the innovation process, and increase the effectiveness of the total research effort. Further, this knowledge will permit the replication by mission agencies of successful centers and technical innovation projects.

First, let us look at the leadership variable, which contains several elements. These include the attitudes of the principal investigator (PI) -- essentially his or her enthusiasm, drive and ambition; the PI's degree of authority for operating policies and decisions; the university standing -- the capability of the PI in academia as measured by organizational and tenure status, professional society recognition, and prizes and awards received. Finally, 'industry ties' measure the degree to which the PI is recognized by industry, evident from previous consulting and project industrial society recognition. The preliminary evidence from our experiments to date indicates that the successful university-industry coupling leaders need to be enthusiastic and aggressive, have major responsibility for operating policy and have impressive academic industry credentials. Further experiments, however, may reveal a university-industry coupling model that is less dependent upon an outstanding and versatile principal investigator.

Let us look at university compatibility, which treats the response of university researchers to opportunities for industry or enterprise links. The university compatibility variable includes the question of whether there is an existing university-based industrial program accompanied by a clearly defined patent policy, a high or low technology content of research needed by industry, the orientation of the faculty towards the industrial research, and the previous experience of the faculty -- for example, whether or not they have had any previous industrial background. The importance of the center to the university, and the administrative freedom of choice by faculty members in industry research without penalty within the university are also factors. The evidence to date shows that successful university-industry couplings are found at universities with a history of high-quality industrial research.

The last variable is the industry characteristics, the interrelated economic and technological factors underlying the response of firms and industries to university research capabilities. These factors include the industry's R & D experience (executives with technical degrees), market power, firm size (large companies being needed for certain projects), profitability, level and frequency of university contacts, and the industry's need for trained engineers and scientists. In this category we are seeing much more interest from industry, and a recognition that success and growth depend on technological advances. Our experience has shown that successful university couplings have larger, more profitable firms as sponsors. This supports the theoretical position that larger firms are better able to capture the benefits of research. A university-industry coupling model for the fragmented industry case has not been developed, although the social benefits in such a model are likely to be high.

Our findings to date have shown that successful university-industry coupling requires an outstanding leader. Universities with a long history of industrial research are needed to attract industry support. Firms with market power are the first to support university-industry research.

Future experiments will examine whether a management approach exists for a successful center that does not depend on a single outstanding individual. This would assure the continuation of the center beyond the career of a single principal investigator.

Secondly, experiments will seek mechanisms by which universities without a long history of industrial research could generate a self-sustaining center.

Thirdly, we want to develop a university-industry coupling model for the fragmented industry case, which is socially important.

Lastly, we will continue to evaluate the variable differences in centers and project cases.

BIOGRAPHICAL NOTE

Mr. Robert D. Lauer graduated from Rutgers University in 1953 with a B.S. in electrical engineering. He served three years in the U.S. Army Signal Corp as a Microwave Officer. In 1956, Mr. Lauer became a member of the technical staff at RCA Research Laboratories where he did applied research on electronic circuit design and magnetic video recorders. In 1963, he joined Electromechanical Research Inc. as head of a magnetic shaft position encoder group and was general manager of their Aerospace Division from 1968 to 1972.

Mr. Lauer has been with the National Science Foundation since 1972 and is currently the director of the Industrial Program, which is responsible for the University Industry Cooperative Research Centers, the Technology Innovation Projects and the Small Business Innovation Research efforts.

Dr. George E. Dieter, Jr.
Dean of Engineering, University of Maryland

You might have gotten the impression this morning that the business of industry-university interaction is easy. From my experience it is not. I am going to tell you a war story, which involves what by all odds was a significant-scale experiment in multidisciplinary, design-oriented engineering graduate education. It was called the Processing Research Institute, and was quite different from Nam Suh's operation in organization and scope. In hindsight, it probably best compares with what might go on in an Engineering Experiment Station.

The Processing Research Institute (PRI) was started in May of 1971 with a grant from the RANN section of the NSF. The author of this noble experiment was Milt Shaw, who served with distinction on the MIT faculty for many years and later at Carnegie-Mellon University. It was his idea that PRI would be interdisciplinary and would work with industry in a project-oriented graduate program. The interdisciplinary aspect involved three departments: mechanical engineering, chemical engineering and metallurgy. It was organized around a board consisting of a full-time director, in which capacity I served, the three department heads, and three faculty members from those departments.

Concerning the introduction of balance in the engineering program, it is important to provide an environment in which engineering graduate students do real engineering problems, and I hope you agree with me that we did just that. This was to be done through interaction with industry.

The format was a master's program: a two-year master of engineering program undertaken in four semesters, with the summer in-between an integral part of the program. A key issue was to insure that the projects which were paid for by industry had equal value in the curriculum to the standard courses taken by the students. The course work was not too different from that which a student might take as a master's student in mechanical engineering or metallurgy. There was an interdisciplinary design course, and if the student wanted to build a special curriculum there was an opportunity to do that.

The mix of students involved in this program over five years came from several departments: chemical engineering, mechanical engineering and metallurgy materials science (an itinerant civil engineer also snuck in). The number of students was not large, and we were kind of tough on them. If students did not participate and really earn their salt they were asked to withdraw, and a number of them did.

The major faculty participation was in the mechanical engineering department (Dr. Shaw was chairman of mechanical engineering), followed by metallurgy and then chemical engineering.

The distribution of effort was, of course, not uniform; we had one soul who was a real trooper when it came to industry interaction, and five faculty who really participated in a major way. Overall, the number of faculty who participated over five years was about half the number of faculty in those three departments. No one had to participate. Those who did were faculty with expertise to offer and an interest in getting involved in real, industry-sponsored problems.

The number of projects per year was in the neighborhood of seventeen to twenty. The total value of the sponsored projects over five years was more than two million dollars. There was a matching contribution from NSF funds, which had a significant effect in getting companies into the program. A total of thirty-nine companies sponsored sixty-six distinct projects. As you will see a little later, one of the things that characterized these projects was their fairly short duration. The average cost of a project was about $28,000.

There was a wide distribution of industrial sponsors. They were not all Pittsburgh-based firms, by any means. One of the things we proved is that you can certainly do this type of thing without being geography-dependent.

We have heard time after time that it is much easier to interact with large corporations, and very difficult with small firms. Surprisingly, a number of trade or technical associations showed up on our list of corporate sponsors, and this is because they are used to interacting with universities. They have done so for a long time. Toward the end we interacted with a couple of the federal agencies, which I will talk about. Most of the projects were just one year in duration, or one year with extension into the second year. It was rare to have a long-term commitment from a company. The companies were interested in value received, and wanted to be sure that they were getting something for their money.

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Our technical problems were in the automation area. Some of them involved actually building prototype designs or taking them to the proof-of-concept stage. Some of the larger projects cost well over $100,000. But in general they were smaller, consisting of one graduate student with a faculty advisor and appropriate technical help.

The reason that the Processing Research Institute can be considered a "maturing experience" is that the university, in the final analysis, chose not to continue it as one of its major functions. We needed something like $100,000 of front-end money from year to year to provide for the educational, organizational and marketing functions of the institute. And that was hard to come by in the particular year when the decision had to be made. Why was this the decision? Well, I can only speculate on a number of reasons, but quite frankly the PRI was not glamorous or sexy in the context of what was valued at that time at the university. It was in 1976-77, before the productivity issue became a hot item. However, the idea of the two-year master of engineering program caught on, and proved its usefulness through this experiment. The mechanical engineering and metallurgy departments introduced their own two-year programs. They did not need an interdisciplinary program like the Processing Research Institute to do these things. We are talking about the tug and pull that goes on in the university between the strength of the departments, and the ability to support an interdisciplinary program across departments.

Another thing is that industry support was not all that easy to come by. The average value of a project was $28,000 per year. But with relatively little effort, we generated several federally sponsored projects, whose average value was $68,000 a year. These were more of an applied type, very comparable to the kind of projects we were doing with industry. So, from the cost-benefit point of view of a dean who was pretty well pressed to come out in the black, PRI was not the best place to spend his resources; and the major resource you have is the faculty. Another thing is that at this time RANN was being dismantled, and our friends at the NSF, much as they wanted to help us, did not know what to do because their goals were up in the air. The timing was very bad. The university was at that time expanding the Mellon Institute into the Carnegie-Mellon Institute of Research, which in some ways is in direct competition with this kind of project, although it is not as heavily integrated with the educational program.

There was an overall problem of commitment on the part of the three department chairmen, who started out saying that PRI was a great idea. All three of them had gone somewhere else by the end of the program. The most successful PRI faculty did not receive tenure. Although some faculty involved in the program did, there is no question that those who participated most and put their hearts and souls into it did not get tenure.

The mission of PRI, in retrospect, was much too broadly defined. It was supposed to do anything that was do-able, and make for good education within the three departments, and that is a very broad scope. It was not backed up by strong basic research in the processing area; no university at that time was really doing strong research in processing. PRI did not have the necessary strong tie back to the departments. Because the mission was so broad, it required a major marketing effort, and the funds for this were part of the up-front money needed to keep it going. And as I said, there was potential competition with the Carnegie-Mellon Institute of Research.

Now, what would I do if I were to do it over again? I would look for stability of leadership. I would get a "blood pact" from the participants to see the thing through. I think that a real institutional commitment must be made at the beginning of any venture such as this. That involves money; not a lot, but some. I would tend to work with a cadre of tenured faculty who had an identified commitment and the needed expertise. These people will be hard to find, but I think they exist in many faculties. They may not be the real stars right now because they are perhaps submerged by the different emphases in engineering education today. But it is worth looking for them. Then I would try to develop a vision narrow enough so that the marketing could be accomplished efficiently -- one of Nam Suh's major accomplishments in his program.

The question of financial support is central; nothing will get done without money. This can be in the form of tax incentives for industry, or some kind of federal matching funds program, or one of the other schemes proposed -- but the money has to be there or you will not get the attention of the university.

Then, there is the problem of attracting the graduate students. I feel that to do real project research, research close to industry, you need a very major time commitment from the students. If you are trying to get the project closer to industry's time scale, you must have more of the students' time. A two-year program tends to be the best model for that, but is certainly not the most cost-effective from the viewpoint of the student interested in getting a master's degree. You need to make this an elitist kind of thing, and put excitement and enthusiasm into it that will attract students. Perhaps the way to get these students may be from the pool building up now in industry. As all of you educators here know, many of our best students are no longer going to graduate school after getting their B.S. They are going to industry at very attractive salaries, and I suspect that some of them are disillusioned. They now feel that maybe they ought to have gone on to graduate school; that perhaps they missed their chance. I think we may have a very viable resource building up here that, through clever support mechanisms, could be brought back into industry-university interaction.

Finally, I come back to the major problem of matching university expertise with industry's needs. Wouldn't it be great if there were some kind of national problem-pool, a clearing house where the whole thing was sorted out, maybe on a geographic basis? People who were really interested could then begin to pull the expertise out of the faculty and begin to tackle some of these problems. These are my ideas on industry-university interaction, and I hope they stimulate some comments later on.

BIOGRAPHICAL NOTE

Dr. George E. Dieter, Jr. was educated at Drexel University (B.S. in metallurgy engineering) and at Carnegie-Mellon University (Sc.D. in metallurgy engineering). He served at the U.S. Army's Ballistics Research Laboratory in Maryland from 1953 to 1955, and worked as research engineer to research supervisor in physical metallurgy at DuPont's Engineering Research Laboratory in Delaware from 1955 to 1962. At Drexel University from 1962 to 1973, Dr. Dieter served as head of the Department of Metallurgical Engineering and dean of the College of Engineering. Dr. Dieter was professor of engineering and director of the Processing Research Institute at Carnegie-Mellon from 1973 to 1977, and has been dean of the College of Engineering at the University of Maryland, College Park, since 1977.

Dr. Dieter has been a consultant to TRW, Inc., Scott Paper Co., Air Reduction Co., and Roy Weston, Inc. His many governmental activities include membership on panels, committees and advisory boards affiliated with the National Science Foundation, the Atomic Energy Commission, the National Academy of Sciences and NATO. He has served on numerous educational and advisory committees, including the Education Committee of the American Institute of Mining, Metallurgical and Petroleum Engineers, and the Engineering Accreditation Committee of Engineers' Council for Professional Development. Dr. Dieter is an active member of many professional societies, and has received many professional honors and awards. His research and teaching interests include mechanical metallurgy, materials processing and manufacturing, technology and society. Dr. Dieter's research activities include Program Director, NSF RANN Grant to Processing Research Institute, 1973 to 1977; Program Director, Sloan Foundation, Creative Engineering Design, 1970 to 1973; Program Director, NSF Departmental Development Grant, Materials Engineering, 1967 to 1972.

Professor James D. Bruce
Director, Industrial Liaison Program, MIT

To some extent, I feel that I am preaching to the converted because all of you are here precisely because you are interested in cooperative research and in interacting with universities. As I listened to the speakers this morning and to the panels this afternoon, I found my own remarks being eaten away slowly but surely. I think that this speaks of the uniformity of many of our feelings regarding the need for cooperation and the ways to go about it. I was impressed with Bob Lauer's analysis of the barriers that we find as we attempt interaction between universities and industry. The issues of different research objectives, of different time scales, of proprietary versus public information, of patents, and of communication are all things that we face daily as we interact with our industrial colleagues. But these barriers have been and can continue to be overcome successfully, if we identify people who are committed to work in these particular areas.

There are certain prerequisites for any involvement between university and industry. First, any involvement, interaction or cooperation must be relevant to the university's main mission. The mission of the university is education and the discovery of new knowledge. Once we begin to step beyond that we encounter problems. It is true, as Herb Richardson indicated earlier this afternoon, that the idea of what constitutes education and what constitutes the discovery of new knowledge is a moving target. The ideas that were prevalent in the 1930's were modified in the 1940's and have continued to change. Today we see the pendulum swinging back from basic science towards the more applied areas, areas directly related to industrial and societal needs. Second, there is always a problem on the university campus of facilities and staff. Do we have the people? Do we have the equipment? Do we have the space to conduct the necessary or the desired program? And finally, a question which I think is wrapped up in the other two: does the proposed cooperative program reinforce our teaching and research programs?

Now, if you were to look around the university campus today you would find many examples of interaction with industry. We have heard them enumerated throughout the day. MIT is particularly fortunate in that the concept of interaction with industries stems all the way back to our charter in 1861; we have a chartered objective to interact with industry to our mutual benefit. As we look around this campus, we find that there are many dimensions to this interaction. Some I would call casual: collegial interaction and the passive exchange of information. Another dimension I would call representational: many representatives from institutions sit on various boards and committees here at MIT. Similarly, university people participate in industrial committees and boards. Then there is the whole class of interactions that are substantive: the roll-up-your-sleeves-and-get-to-work activities.

These different interactions address two basic objectives. The first is the provision of students who will be employees in industrial concerns. Second is the generation of basic knowledge, as well as applied knowledge, that can be carried forward to industrial use. I have a long list of the various interactions I have observed around here. Many of our students do go out and work in industry, an interaction we cannot neglect. They are our product and we should be concerned that our product meets the needs of industry. Along that line, there are cooperative education programs, and we at MIT have two, one of which is among the oldest in the country: the course VI-A program in electrical engineering. Our students go out and spend a part of their educational program working in industry, in close relation to a faculty member who is assigned to oversee their work at that company. Many of our faculty interact in consulting relationships with companies. I have spoken about board memberships and committee memberships from the university to the industry, and from industry back to the university. We are beginning to see a greater exchange of faculty and research staff between university campuses and industry; not just for a few days, but for weeks and semesters and even a year. The idea of the industrial sabbatical is growing, and I would argue that it will eventually grow even beyond that which many of us envision. In some circles it is becoming an inappropriate concept, but I think I would be remiss if I were not to mention the interaction that comes from industry to the university in the form of philanthropy. If you look about a campus such as MIT, and I think this is true of any of the great private institutions in this country, the fields in which we are involved are to a large measure determined by the philanthropic gifts that we receive. Many of those come from industry either in the form of direct gifts from the company or from the founders of the company. We would not be in many of the fields that we are in, were that not so.

I want to mention three particular interactions that I think are growing. In looking back at the amount of the industrial research done on the MIT campus, particularly in the years since 1950, I see a monotonically increasing function, not only in dollars but also in percent of total. That is very encouraging, because for many years many of our faculty were not interested in industrially-sponsored research. Such research couples us to the world of industry and provides great insight to our students. We are going to see a greater number of individual, industrially-sponsored research projects in the future, which result from an individual company sponsoring the work of one or more faculty members in a particular field. If we look about this campus, we find such sponsorship in very basic areas; areas where the pay-off of the research is at a point in the future. We also see projects where the pay-off is of a much shorter-term nature. In addition, companies are becoming interested in licensing a particular patent or know-how that has been developed on campus, and then sponsoring work in the same field here as part of the process of transferring the technology into the company.

Much has been said today about research consortia. We have heard and we will hear again in a few moments about Nam Suh's Polymer Processing Program and its success. I think it is a model that we will continue to observe and to emulate in other fields around the Institute. Other examples, however, abound here. They involve not just one faculty member or a small group of faculty and students and industry, but much larger concerns requiring a bigger umbrella. One that comes to mind is the MIT Energy Laboratory. We do not think of the Energy Lab as an industry-university cooperative venture, but it is just that. This becomes evident when you look at how its pieces work together, at the source of the funding, and at the aim of the Lab to provide an independent view on a particularly important segment of this nation's technology and technological needs. Out of this laboratory have grown two interesting centers -- the Center for Energy Policy Research, which is funded entirely by nonfederal sources and looks at policy-related issues in the energy field, and the Center for Health Effects of Fossil Fuel Utilization, funded by government and industry, which looks at the toxicological issues of our utilization of fossil fuels.

We have just announced here on this campus that we will build a VLSI facility. This will be a state-of-the-art facility and industrial support will be required for its operation.

One could go on and speak of the need for university-industry collaboration in continuing education programs. MIT has had a long history of providing a number of spaces in classes for students who come from industry. We also provide video-taped instruction. But I am not convinced that we have settled upon a model that really speaks to industrial needs, and we are being challenged by some of the industrial leaders in greater Boston to get our act together. I think in the coming years we must do that.

I would like to mention another set of programs, those of the Industrial Liaison Program (ILP). ILP has the charge to provide a broad transfer of knowledge of all the research that is going on at the institution to the industrial community. My responsibilities at MIT are to oversee two programs, the Industrial Liaison Program and the Associates' Program, which together are both the largest and the oldest of liaison-related programs in this nation. Through these programs MIT provides a window for its member companies, and there are roughly 200 in the Liaison Program and sixty in the Associates' Program, on the technology developed here. The idea is to disseminate that information as rapidly as possible.

Finally, let me share one concern, which I raise as a question because I do not think we have an answer yet. How do we address the needs of the smaller companies, the companies whose annual sales are in the range of ten to twenty million dollars a year? Such companies can and do compete effectively for our students. They can and do send students here for continuing education programs. But such a company cannot afford to be a member of the Institute's liaison programs; the fees are too high. For the same reason, these companies cannot afford to participate in Nam Suh's program. They cannot afford to sponsor research at MIT, because they don't perceive the payback to be adequate for them. Yet we know that some of the most innovative companies in the country are these smaller ones. How do we interact with them?

BIOGRAPHICAL NOTE

Dr. James D. Bruce is a professor of electrical engineering at MIT and director of the Industrial Liaison Program.

Dr. Bruce received the B.S. degree in electrical engineering and mathematics from Lamar State College of Technology in 1958. He received the S.M. and Sc.D. degrees in electrical engineering from MIT in 1960 and 1964.

During the 1964-1965 academic year, Dr. Bruce was a Ford Foundation Postdoctoral Fellow in Engineering at MIT. That same year he was appointed assistant professor of electrical engineering. He was promoted to associate professor in 1968, and the following year he was named executive officer of the Department of Electrical Engineering and Computer Science.

In 1971, Dr. Bruce was named associate dean of MIT's School of Engineering. He received his appointment as a full professor in 1973. During the 1977-1978 academic year, Professor Bruce served as dean of the School of Engineering. He was named director of the Industrial Liaison Program in January 1979.

Dr. Bruce has consulted extensively for organizations such as Development Analysis Associates, Inc., the Raytheon Company, the Cambridge Research Institute, the Oak Ridge National Laboratory, the Honeywell Radiation Center, and the Charles Stark Draper Laboratory. He taught digital signal processing in Bolt, Beranek and Newman's Advanced Study Program from 1968 to 1970 and a similar course for IDMON Associates from 1970 to

1973. His recent consulting has focused on the introduction of advanced technology into developing countries.

Among Dr. Bruce's current research and professional interests are digital signal processing and information management systems. He and his students have developed several on-line computer systems to assist in the management of an academic department's resources, and some of these programs have been implemented at MIT.

He is a senior member of the Institute of Electrical and Electronics Engineers and the American Society of Engineering Education.

Mr. Richard W. Reynolds
Director of Manufacturing Technology, Xerox Corporation

Perhaps I can bring a different perspective to the discussion as a member of the Manufacturing Research Community in industry, and as one dealing with a very specific consortium -- the one headed by Nam Suh. There are a number of other industry-university interactions that flavor my remarks as well.

Basically, the goals of research in industry and in the university are different. The goals of industrial manufacturing research are very short-term; we want a quick pay-back. The university wants a generic problem to work on, and has a longer-term vision. Ours tends to be narrow in focus. Industrial research is very applied; the university's is very theoretical and basic. We tend to want our projects to remain as proprietary trade secrets; the university wants them in the public domain. Industry is primarily interested in implementing its projects to get a cost savings in the near term. The university's primary goal is to educate. With these diverse goals, one would think that it might be almost impossible to achieve success in joint ventures, but I have some thoughts on how this partnership can be made successful.

First of all, and you have heard this earlier today, there must be an overriding motivation on the part of both organizations, the industry and the university, for this to be successful. The top management in industry must support these efforts both from a financial standpoint and also by providing the personnel to do the proper liaison. There must be high-level commitment within the university. It is important to look for early spin-offs -- benefits that can be implemented with perhaps modest improvements in the near term, and aspects that can be pointed to as definite mutual benefits of the interaction. The planning this entails has been discussed in detail. I would like to emphasize that it is necessary to be specific about the goals of each project. In order for the projects to be successful, both organizations must have a common understanding of the results that are being sought.

I would recommend staying away from the corporate cornerstones of technology. For Xerox this means staying away from studying xerography. Otherwise you will run into proprietary problems, particularly in these consortium programs. Place multiple bets. Research is risky business in any circumstance, and there is nothing wrong with having the same kind of project going on in two different universities, or multiple projects at the same university. Plant the seeds, fertilize them and cultivate them. Follow up on the project frequently to assure that the mutual goals are being maintained. At Xerox we appoint a single contact for each project that we sponsor, someone who feels responsible for making that research successful. Part of his performance appraisal is the examination of the success of his project at the university. When you accord that kind of responsibility you find the concerned individual elevating the problem areas of the project to management. Management then gets in touch with the university management, and the research gets back on track. It is easy to get off track when you meet only once a quarter; in between, things can go astray. But if you give a particular person this kind of responsibility, he can make it his business to interact with the research on a weekly basis.

Of course, one of the real side benefits we receive from these interactions is the opportunity to get to know prospective candidates for employment.

In closing, I want to mention that, although we have not yet implemented a major project at Xerox from the Polymer Processing Program, there are three fairly major projects that will move into our own laboratories this year that were initiated as part of projects at the university. Major financial benefits could be achieved from these starting in 1981.

BIOGRAPHICAL NOTE

Mr. Reynolds is in charge of Xerox's Manufacturing Research and Development Function, which he established. Some of the innovative management techniques he has evolved are corporate-funded manufacturing research, the "Seed" project concept, Enabling Technology concept, and cooperative research with universities and research institutes.

Mr. Reynolds received his B.M.E. from Cornell in 1953, and studied nuclear reactor engineering at the Hartford Graduate Center in 1957 and at Rensselaer Polytechnical Institute from 1967 to 1970. He is a member of the American Society for Metals, and is adjunct professor, metallurgy, at Rensselaer.

From 1963 to 1970, Mr. Reynolds was chief of Manufacturing R & D at Hamilton Standard Division, United Aircraft. He has worked as research engineer, manufacturing engineer, plant superintendent and general foreman.

DISCUSSION

David Noble: I am an historian of technology and industry. I have great sympathy for a lot of the things that have been said, but I want to share with you some of my concerns. I think that we are embarking upon a major transformation in the relationship between the universities and the society as a whole. There are only two other academic transformations of this magnitude in this century.

First, you have been talking a lot about the crisis in innovation. I want to remind you that this has never been demonstrated. It is rather suspect. Second, the correlation between innovation and productivity is ambiguous. Third, the correlation between regulation and innovation is ambiguous, at best. Fourth, the correlation between innovation and the competitive problems we are facing as a nation is ambiguous, at best.

The enthusiasm that I hear, and in part share, for what we are calling cooperation is understandable. But we should not believe our own rhetoric that claims there is a crisis in innovation, because we can get carried away in the details and lose sight of what all this is really about. I think that universities like MIT, research universities, are interested in cooperative ventures because they provide research funds, and offer a way to cut through all the government red tape in research activities. Industry is interested in cooperation as a part of its larger campaign to improve the climate for investment, to deregulate -- in both environmental and occupational health and safety areas -- to change the patent system and the antitrust laws, to get tax breaks, and, as a means of receiving state subsidies indirectly through the universities, to avoid the attendant state control. In addition, industry can considerably enlarge its resources rather cheaply by cooperating with universities, since it can acquire resources created by decades of social investment for mere operating expenses. The government is enthusiastic about cooperative research for various reasons. But with all due respect to Frank Press of the OSTP, Bowman Cutter of the OMB, and Jordan Baruch of the Commerce Department, their Domestic Policy Review recommendations are for all intents and purposes indistinguishable from the recommendations of the Industry Committee on Economic Development. They are basically straightforward business recommendations, endorsed by the Administration.

I see three dangers in the type of cooperation being discussed here. One pertains to the universities, and that is the need for academic freedom. It is rather quaint, but it is very important. With more direct industrial subsidy to universities there will be (and is already) a considerable restriction of views, and greater conformity to management objectives. Second, the type of cooperation we are talking about will tend to reinforce deregulation. (I do not see anyone from regulatory agencies or public interest groups here.) Tied to that, I think there will be an increased concentration of economic power stemming from these cooperative ventures. Third, the direction of research itself will be influenced. In the biomedical area, for example, the relationship between Monsanto and Harvard has already influenced the direction of cancer research being done there, moving it away from the occupational and environmental causes of cancer.

Finally, we have talked a lot about computer-based manufacturing, CAD CAM systems, and the like. The direction of that area of R & D continues to reflect only management objectives and ignores social effects. There is no one here from labor. We are talking about retooling major industries; where is labor? Although I am highly enthusiastic about a lot of what I have heard, I think this conference is an indication of what will happen if we don't insure a broader base of discussion and participants. As I already indicated, there is no one here from the regulatory agencies or environmental or consumer groups. If this is the pattern that will be set for cooperation, I think that we will find it difficult to argue that it is in the interest of society as a whole, and not just the well-endowed and powerful parts of society.

George Reichenbach: Thank you for your comments. We will take them into our deliberations. I do not think that we should try to respond to all that now, but I understand the points that you are making -- and mainly they are very good points.

Speaker not identified: I would like to direct my question or challenge to Mr. Lauer. The information that you presented showed that, so far, we do not know how small companies can work with universities efficiently. Dr. Dieter has found the same thing. If that is correct, can you justify the amount of money in the NSF budget that is set aside for the specific purpose of coordination between small companies and universities?

Robert Lauer: The small business innovation program is a separate program in cooperative research. There, the transfer is directly to the small businesses themselves.

Questioner: Do you have information on the efficiency of that?

Mr. Lauer: It is a relatively new program. It is only two years old now, but we are gathering data, and the companies that have gotten awards are succeeding very well in getting venture capital, and in some places are being absorbed by large companies. In fact, that is one of the things that we are concerned about; they are so successful that they are absorbed by large companies. So in one sense we may have created a monster.

Nazir Bhagat: I have heard a great deal here about the difficulties faced in trying to do "the technological research," and also about the mechanisms by which this country has accomplished much in the past. There has been very little discussion of areas where increased research is needed. I would like to ask the panel: Are there any critical problem areas, or research agenda currently neglected, which unquestionably require a cooperative approach?

Dr. Reichenbach: I will venture a partial answer. The industrial firms have identified many areas, which they are researching and supporting. I believe the Jordan Baruch committee tried to identify generic areas. They produced a long list of potential areas for cooperative research, and I guess that is the best effort to date.

Mr. Bhagat: I would like something more concrete in identifying specific research gaps that call for a cooperative research approach.

James Bruce: One of the problems is really one of the issues in Bob Lauer's model. Right now, in order to get a cooperative program going, you must find a champion on the university campus. You have to find that person. Now, once that person is identified you can go to the exercise of putting together the funding and the industrial organizations that will be part of it. But until you have that person identified, you are whistling in the wind. You can parade the money and the various research agenda, but the thing that will determine your work is that man or woman who is willing to be out there on the line.

Mr. Bhagat: The selection of that individual depends or may depend on the problem that needs tackling. I think that you cannot start with the man and tell him to look for a problem to tackle.

Dr. Bruce: He will bring the problem.

Dr. Reichenbach: Many of us feel that innovation is a nice regular marching process. You do basic research, and based on that you predict that certain things will happen. You test it out, certain things do happen, and eventually you have a product for the marketplace. Maybe that happens. But in the experiences of the members of this panel it hasn't happened. Rather, basic research brings people to a certain level of understanding. Then, this key person that was just mentioned suddenly has an inspiration. He says, "I am not quite sure why this is going to happen. But I make an extrapolation and I think that I can do something that no one else has done." He cannot prove that the idea will work, though. Then he goes around and sells his idea, saying, "Come bet your money with me; I think I can do it." Later on, some basic researcher may explain why it worked. But I do not think we ever see new innovations come the way they appear in the textbooks. It is a very muddy thing. It is very hard to know what the good patent is, and what the good idea is when it is first reached.

Speaker not identified: In our experiments, industry votes with its money on the problems it considers important. Where industry puts its money is the determining factor.

Speaker not identified: I am looking for a frame of reference on this. On the one hand, I think the whole bottom line is national encouragement of innovation. On one side you have technology that has been developed quite well in areas like Route 128. On the other, you have the Fortune 500 companies. They have already chosen sides, and are doing quite well at the universities, and they bring in people as consultants and that earns them extra credits. What is the extension of these two things that will provide additional linkages, or new slants on linkages, between universities and industry?

Dwight Baumann: We can compare or contrast industrial support to the alternative of government putting money into a so-called government laboratory. That has been mentioned this morning as a mechanism that worked well in the NASA and the NACA and in the agriculture department. I think that we will find that these government labs helped foreign industry as much as they did ours. There were as many of the NACA numbers in the Zeros and Messerschmidts as there were in our airplanes. The problem is that government laboratory results have to be published, and our industry does not read. But foreign nationals do read, and so the money that we spend in industrial laboratories, the so-called nonprofit, does get spread around the world very fast.

On the other hand, if we put it into universities where there is an input of people, the result is people. And those people start industries, and carry their university knowledge with them when they go to the companies and work there. I think that it is very important that we recognize that the reason Detroit happened was not because it was a good place to build automobiles, but because Henry Ford was born there. The same thing still happens today. People, when they have confidence and are operating in an environment where they can do real and vital things, continue to do those real things, and do them wherever they are living at the time. If we want industrial development in this country we will do something that deals with groups of people, and we will make damn sure that there is a throughput.

III. THE PRIVATE SECTOR

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Resource Allocation and Technological Innovation

Dr. Norman Hackerman
President, Rice University

The innovation system has functioned to date more randomly than otherwise. It is claimed with increasing frequency that if this system were simply better organized, innovation (and productivity) would bloom again in resplendent fashion. The answer to that proposal is neither a rousing affirmative nor a sour negative. It seems clear that greater organization is required at the end that produces material items, but this need is less clear at the less structured input end, where the intent is to induce original ideas. Such organization as is necessary should simply provide for the identification and enhancement of the proper individuals. This process is far from efficient, and will likely remain so.

The scarcity of materials is either current or imminent, and there is no question of this culture's critical need for science and technology. The stress of debate over apportioning basic science support between advancing the fundamentals and closing the gaps will help keep the system active and viable. The struggle to get a proper share of the common, as well as localized, wealth will also continue.

The question of the individuals who become part of the enterprise, and the roles they fill, is the single most important aspect of the problem. Structuring personnel needs to personnel supply is probably satisfactory for the team approach to problem solution, but it is unsatisfactory in providing the overall setting for the occasional crucial idea.

I am pleased to be here this evening to discuss the innovation system in this country, the need for cooperative research to stimulate innovation and productivity, and some existing and possible new mechanisms for carrying out such work.

We are all aware of the concern about a slippage in this country's lead in innovation. In the summer of 1979, *Newsweek* featured a major article entitled "Innovation: Has America Lost Its Edge?" In October 1979, after completion of a domestic policy review on the subject, President Carter sent to the Congress a message on industrial innovation initiatives. In the House of Representatives, an Ad Hoc Task Force on Industrial Innovation has been formed, chaired by Representative Les AuCoin (D - Oregon). In December, the task force joined with other members including Representative George Brown, the chairman of the Subcommittee on Science, Research and Technology, in presenting a colloquy on industrial innovation on the floor of the House of Representatives.

Industry, including small business, and academia and government are involved. So, too, is the American Chemical Society which convened a task force on innovation. In December, the National Academy of Engineering's Colloquium on Industrial Innovation and Public Policy was held. The Dow Chemical Company sponsored a Conference on Advances in Chemical Science and Technology in October 1979, to bring together academic chemists and chemical engineering and industrial executives. A second conference, sponsored by Air Reduction Company, is scheduled for fall 1980, and the American Productivity Center will hold a similar conference in April 1980. Today's conference has been organized to consider the issues involved and to formulate and recommend policies for consideration by decision makers in academia, industry and government.

Not everyone, however, believes that the U.S. has lost its innovative edge. An article in a recent issue of Hughes Airwest *Sundancer*, "Mr. Yankee Doodle Dandy" by Dennis Meredith, suggests that there are many independent inventors in this country and that they need only a little help to bring their ideas to the marketplace.

What are the forces driving the national concern about technological innovation? One is the disappointingly slow growth of American productivity in recent years. Another is the evident success of foreign competitors, notably the Japanese and the Germans, in competing with us for markets for industrial products. Still another is the challenge to our ability to innovate stemming from the scarcity of energy resources. (The resultant high cost of energy may be a driving force, but basically it is recognized as a realistic readjustment in values.) Shortages of strategic and industrial minerals and metals such as cobalt, chromium, manganese and platinum now exist. The U.S. imports approximately 90% of each of those metals, and it is likely that we may be at the same point with regard to these nonrenewable resources as we were with respect to oil ten years ago. If so, we must begin taking steps now to avoid an economic and strategic disaster. There is no real evidence of a reversal of the trend to require technology in the high technology societies, nor does it appear that the developing countries will fail to follow the same course. So a strong technology is vital.

Before examining ways to meet these problems, I would like to say a few words about innovation. Most of us agree that the technological innovation process consists of that range of activities involved with conception, research, development and diffusion of new or improved products, processes and services for private or public use. In a simple model, the sequence proceeds from basic science to applied research and development, then to technological innovation, and finally to economic growth and an increase in social well-being. Of course, the actual system is more complex and subtle than this implies, and includes details that may not yet be properly appreciated.

The system is a highly interactive network where science and application are mutually reinforcing and information flows both ways. The overall level of activity in the network is not only a function of application opportunities, but also of scientific and technical advances. It is certainly affected by economic incentives and financial aspects as well as by inquisitive, thoughtful and knowledgeable people.

Science may provide a seed that flourishes in a particularly fertile industrial setting, or an industrial problem may fertilize academic thought, or both may occur. The convergence of helpful circumstances sometimes occurs and sometimes does not. Innovation is not induced singularly; it is multifaceted. Often applied science or development will open new avenues of inquiry for basic science. Conversely, all basic science cannot be expected to lead to technological advance, directly or indirectly.

The "mix" of basic science and technology varies with the particular problem being investigated, and some innovation occurs without any basic science perceptibly preceding it -- i.e., the inventor draws on his or her own background of knowledge. An innovation may lead to scientific discoveries, which in turn may combine with others and with technology to lead to further innovative results.

The major elements of the innovation process include the research community (most frequently, academic institutions), commercial institutions (ranging from major industry to small businesses and individuals), investors and financiers, and now the Federal Government. The universities, in which basic science has often originated, engage primarily in work that will advance understanding, is longer range in nature and normally does not have a quick payoff; indeed, university work may involve no risk, in that its purpose is to increase understanding. The universities' major resource is bright people, including graduate students who are there for educational purposes but who also provide a relatively inexpensive labor source. (This is not denigrating -- it is akin to apprenticeship or internship.) Further, the universities have "state of the art" instrumentation, even though the components may be aging, because of ingenious improvisation.

Industry, in which applied research as well as development usually takes place, tends to support work of a shorter range with a relatively quicker payoff. Industry's major resources are bright and educated people, capital and directed drive. Small businesses are a unique part of the industrial system, and make a disproportionately large contribution to innovation. For them, money is a problem more than an available resource; their strength lies in the innovative people who are frequently found in this setting.

Governments (state and local, as well as federal) have both direct and indirect influences on the innovation process. They act as facilitators through financing of R & D, and exert both inhibiting and facilitating effects through patent, taxation and regulation policies, all of which affect economic and financial aspects of the process.

There are many questions we can raise about the innovation process. For instance, can we identify gaps in the system and devise means to close them? At which points can leverage be applied effectively, and what should be the nature of the leverage? Can the time span of the process be shortened? Do our existing institutions provide an adequate environment for technological innovation? Who should finance the unstructured search for basic knowledge? How much applied research should be undertaken in the university setting? Should it include development? To what extent should industry be encouraged to increase its performance of basic science? How? Are additional incentives needed to increase graduate student enrollments in certain fields, and are these the responsibility of academia, industry or government? Would some reorganization of government to encourage innovation be helpful?

Some federal reorganization has already been suggested. An independent agency, the National Technology Foundation, is one suggestion. It would unite and coordinate elements within the federal sector involved in innovation and productivity, university industry linkages, high technology small business, technical information and data acquisition, and transfer of technology and information to the private sector. The expectation is that a separate foundation for technology would encourage truly unique technology programs, and enhance a creative environment. Undoubtedly it is looked upon as a potential home for cooperative research programs involving academia, industry and perhaps government.[1] On the other hand, such an agency would tend to deal with current issues and might lose sight of the long-range needs of the country. Some believe that it is impossible (and perhaps unproductive) to draw or attempt to draw a sharp distinction between scientific and engineering endeavors. It may be that further expansion of NSF programs in basic engineering science and applied science would better accomplish the purposes of the proposed legislation.

Another issue deals with the apportionment of basic science support between advancing fundamental science and closing existing gaps. This is a matter of importance to all concerned, but it will not -- nor perhaps should it -- be settled. The stress and tension of debate, I believe, help maintain a viable system. Continued discussion of the proper share of the common wealth, as well as 'localized' wealth, for the enterprise as a whole is also to be expected. This debate and discussion is apt to be less difficult and frustrating at the output end of innovation since the utilization portion of the spectrum is more easily understood and accepted.

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[1] As of publication (summer 1982), not being actively pursued.

How well does the innovation system work? To date, it has functioned in a largely random or stochastic fashion but has served well, yielding a good cadre of educated and trained people to provide many of the large and small advances of the century. A point made with increasing frequency and intensity today is that, if the system were only better organized, if the linkages among the elements were improved, innovation (and its concomitant, productivity) would bloom again resplendently.

The proper response to that suggestion should be neither a rousing affirmative nor a discouraging negative. Cooperation among elements of the system can be explored at many levels: among individuals, among the institutions involved, and between national policies and objectives. In considering these levels of interaction it is important to keep in mind that the approach may be through either a highly structured or a totally *laissez-faire* system. We need to determine the price to be paid for each. It seems clear that greater organization is effective at the end that produces material items; it is less clear that much structure is desirable at the input end. That end is somewhat formless since the intent is to induce ideas and original concepts, both where ignorance is evident and where it is not. This suggests that at the new knowledge end, organization should simply provide for identification and enhancement of the proper individuals for each type of task. This process is far from efficient, but increased efficiency in the form of a better matching of supply and demand does not insure improved innovation, although it may assure improvement in doing assigned tasks.

Training of individuals may be a problem in some areas. For example, industry needs manpower with a liberal education, expertise in science or engineering, and a knowledge of business practice and management. The demand for engineering graduates is now so great that some graduate schools are unable to fill their programs with U.S. students. As a result, foreign graduate student enrollment is climbing. By 1977, 36% of the graduate students in engineering fields were foreign.[2] The implications (both positive and negative) include the following:

--The present level of university-based research may not be possible without foreign student involvement.

--Foreign students provide new perspectives that contribute to the intellectual mix at universities and stimulate new ideas.

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[2] In other fields, full-time foreign graduate student enrollments were as follows: mathematics, 23%; physical sciences, 21%; life sciences, 11%; social sciences, 13%. Source: NSF data.

--Foreign students who remain in this country provide an important industrial resource but constitute a brain drain from their home country.

--With the expanding economy in many parts of the world, a substantial number of foreign students (many federally trained) are returning to their homelands. This further aggravates manpower shortages, especially in engineering and the computer sciences. It is also cause for concern by industry, as technology transfer to other countries takes place through this mechanism.

--By relying on foreign resources we are masking significant national problems; e.g., those of attracting adequate numbers of students to technical fields and developing a balance between research activities and industrial and university employment opportunities.

--Foreign students from some countries concentrate in selected applied areas and can cause both short-term and long-term distortion of research programs.

The longer-range point of view should, however, consider foreign student involvement within the larger context of global development and the advance of other nations in economic growth and technical prowess. In a changing world of limited resources and increased specialization, it is becoming clear that, while striving for national excellence is important, some division of labor among countries is productive. A country that increases its scientific and technical capabilities has a greater potential to solve its own problems, including those of health, food and energy. This does not, however, diminish the substantial industrial concern with this issue.

The individual who becomes part of the innovation enterprise, and the role he or she chooses, are the most important aspects of the process. Here the gloomy tendency is to note the diversion of the "best" or "smartest" individuals to other fields, implying that they should instead stay in the science and technology sector. The outcome of structuring personnel needs with supply is probably satisfactory for the team approach to problem solution, but less satisfactory in providing the overall setting for the occasional truly innovative idea.

Attention must also center on improving and strengthening the ties between universities and industry, the institutions involved in the innovation process. A recent paper in *Science* by Prager and Omenn points out three factors identified earlier by Smith and Karlesky which have led to a weakening of these particular linkages during the past two decades. They include the separation of academic research from perceived industrial needs, the level of interest among university graduates in industrial research centers, and a decline in industrially-performed basic research. These authors also identify and discuss four types of university-industry relationships, including corporate contributions to universities, procurement of services, cooperative research, and research partnerships.

Federal support to stimulate innovation is included in the programs of a number of agencies, among them the National Science Foundation. Its Directorate of Engineering and Applied Science (EAS) seeks to strengthen the nation's engineering and applied science research base and enhance the links between fundamental research and applications, especially in addressing certain selected national goals. The requested fiscal 1981 budget for EAS was $137 million, of which $62.6 million was earmarked for engineering research. This represents a strengthening of the Foundation's engineering activities over a number of years; in 1971, the budget for engineering in NSF was $14.1 million.

Other activities of particular interest in EAS are the following:

--The Industry University Cooperative Research Program which encourages individual cooperative research projects, and thus strengthens ties between universities and industry.

--The Small Business Innovation Program which provides opportunities and incentives for small science- and technology-based firms to perform research on important scientific and technical problems that could have significant public benefit if successful.

--The Industrial Technology Program which sponsors research incentives designed to increase the commitment of U.S. industry to research and development, and supports the establishment of university industry cooperative research centers in generic technologies. The program also supports projects to draw together results of various basic research efforts when it appears likely that a synergistic effect on U.S. technological capability could occur.

The total amount requested in fiscal year 1981 for these last three programs is $38.2 million, a substantial increase over earlier funding via the NSF.

Activities seeking improved understanding of the incentives and disincentives affecting the innovation processes and their management to identify potential leverage points for federal action are supported through the Foundation's Directorate for Scientific, Technological and International Affairs. These efforts are closely coordinated with complementary efforts in other programs.

In fiscal year 1980, President Carter directed the Foundation to work with the Department of Defense, the Department of Energy, the Environmental Protection Agency, and the National Aeronautics and Space Administration to help initiate other industry university programs, with a view to reaching a level of over $150 million annually. The NSF also plans to work with other agencies to determine whether they should establish small business programs, with an eventual total of $150 million in annual funding.

A different type of activity, a national conference to stimulate improved curriculum development in technology management and entrepreneurship, will be jointly hosted by the Department of Commerce and the NSF.

A 10-year Ocean Margin Drilling Program is included in the NSF's fiscal year 1981 budget at $10 million, to be matched by the U.S. petroleum industry. Engineering design and cost estimates for conversion of the Government-owned ship, the *Glomar Explorer*, and the advanced deep ocean drilling system, as well as scientific planning, will take place in fiscal year 1981. Results of these efforts will provide the basis for the final "go, no go" decision on the whole project as a joint venture between government and industry. Total cost is estimated at $700 million.[3]

Whether the efforts enumerated above are the "correct" amount and mix or whether greater inducements will be required to stimulate university industry cooperation, only experience can tell.

Today's conference, through its panels, may identify other arrangements as alternatives or supplements to the existing programs. Among those which I have heard suggested is the exchange of personnel between universities and industry. The physical location of students and faculty in an industrial setting, or industrial researchers at a university, should encourage each to become aware of the problems, needs and capabilities of the other. It is important that the interaction be in-depth and continuing, and that the individuals involved personally identify with and have a high degree of responsibility for R & D projects. They should be aware of the significance of their work for industry and for contributing to the development of new knowledge.

A different kind of alternative is the establishment of university industry research centers within industrial locations. In such an approach, industry would provide the center location and leadership, with appropriate arrangements for university researchers to perform research activities at the center. Important issues associated with this approach are as disparate as antitrust concerns and the formulation of research programs.

The nation's economic well-being requires constant attention by all interested parties to stimulate innovation and productivity. Continuing experimentation, strengthening of the system, and imaginative new approaches by academia, industry and government are needed for the most effective utilization of our resources.

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[3] This project has since been incorporated into the ongoing ocean drilling program

BIOGRAPHICAL NOTE

Dr. Norman Hackerman has been president of Rice University and professor of chemistry there since 1970. Prior to coming to Rice, Dr. Hackerman spent twenty-five years at the University of Texas, Austin, where he joined the faculty as an assistant professor of chemistry in 1945 and became president in 1967. He received his A.B. and Ph.D. from Johns Hopkins University. He taught chemistry at Loyola College and Virginia Polytechnic and worked as a research chemist for Colloid Corporation, Kellex Corporation, and the U.S. Coast Guard.

Dr. Hackerman has been a member of the National Science Board since 1968 and its chairman since 1974. He has been the editor of the *Journal of the Electrochemical Society* since 1969. He is an elected member of the National Academy of Sciences, the American Philosophical Society, and the American Academy of Arts and Sciences, and belongs to numerous scientific organizations. He is author and co-author of more than 170 publications.

In addition to several previous awards, Dr. Hackerman received the American Institute of Chemists Gold Medal in March 1978.

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Academic Research and Industrial Needs

Mr. Thomas O. Mathues
Vice President, General Motors Corporation

The contributions of business to this nation's colleges and universities can take many forms. Some financial support is desirable and necessary, and is a basic business and social responsibility. The shift from government to industry as the primary source of financial support is justified in view of efforts to limit government spending, and in terms of industry's decreasing share in the diminishing funding for research efforts. Financial support for research must, of course, be based on mutual interest and concern, and industrial research efforts must be supplemented by efforts in the academic community.

In addition to financial support, industry can cooperate with academic research efforts by disseminating the results of industrial research work, participating in executive faculty exchanges, coordinating cooperative education "work-study" programs, and making summer jobs available for top students.

Colleges and universities must help students and researchers develop the skills necessary to transfer experimental work from laboratory to practical industrial applications. Few commodities are more difficult to sell than the innovative idea, but these are urgently needed. New directions entail risk, and it is the responsibility of educators and industrial managers to evaluate that risk in light of potential gains.

Foreign competition is a major challenge to American industry today. If domestic industry is to compete successfully with foreign manufacturers, we need skilled manufacturing engineers and managers with innovative approaches to manufacturing processes. Perhaps the most significant challenge to our colleges and universities is the development of programs which would provide graduates well trained in manufacturing processes and able to apply their knowledge to the complex manufacturing requirements of the future.

I would like to offer the views of one company in one industry on the optimum nature of the industrial-academic relationship. In saying that, I am being terribly presumptuous. I am not at all sure that I know what the optimum nature of the industrial-academic relationship is but I will give some of my personal views, and some of those expressed in the company that I represent. I want to extend these general comments beyond my specific responsibilities in manufacturing at General Motors; but I really would not be doing my job if I did not get a bit parochial, as I will later on, and zero in on our manufacturing operations.

There are few goals more desirable for our economy than the goal of this conference: to make "a substantial contribution toward increased national productivity and technological innovation." It is a goal we can attain only through the cooperative efforts of business and government and the academic community. Continued progress and success for our nation depends on our ability to overcome any narrow special interests, and to work together to provide the impetus that our nation needs to grow and prosper.

I have set down seven rather loosely associated ideas which I believe can help clarify the processes of cooperation. Let me first offer some suggestions about how the business community can contribute some of its assets, its knowledge, and its experience to our colleges and universities.. Later I will discuss the contributions that the academic community can make.

Perhaps the most obvious business contribution is financial support. Some years ago, industry provided a substantial portion of the funding for basic and applied research in the universities. But as we all know, for the past few decades most of these funds have come from the Federal Government, with smaller amounts -- in most cases very much smaller amounts -- coming from state and local governments. Industry's financial support for research has actually diminished to a small fraction of the total, and the total itself has diminished. I think this is in part due to the pressures we as a people have exerted to limit federal spending more realistically. None of us has escaped the effects of our inflationary economy, an inflation brought on by too little attention to sound fiscal and monetary policies. Today there is little argument with the view that government spending must be reduced, and more of the financial responsibility for research be placed on the private sector. A company that does not accept a portion of this responsibility is not only abdicating a business responsibility, but is refusing to accept an important social responsibility as well. I emphasize this not because such a relationship doesn't exist, nor because industry hasn't supported academic research and development in the past, but because we need to do more. And, concomitant to this, government should do less.

A second point: just as it is incumbent on industry to provide some financial support, it is also incumbent on the academic community to solicit and attract that support. If industry in general received more attractive proposals from the academic community -- that is, proposals which were admittedly more oriented toward our own self-interest -- then I think more funding would be forthcoming. Thus, to improve this relationship between industry and the academic community, there must be more thought in the academic community about industry's interests, and more proposals brought forward than in the past. I believe industry will in fact respond, and will support more university research as a result. We would rather have colleges and universities come to *us* for help, rather than seek it solely from the government.

I want to emphasize that we should cooperate in areas of mutual interest and concern. Our resources simply will not let us support everything. If a researcher, for example, is seeking support in the field of philosophy, General Motors will not shut the door the moment we hear the title of the project. But this researcher may be competing for available funding with someone investigating, perhaps, a more economical method for extracting petroleum from oil shale, and the latter would be nearer and dearer to our hearts, as you can imagine. It is a matter of matching the research interests to the interests of industry. We do not shut the door on projects like philosophical research, just as we did not shut the door on a grant for a study of personal privacy, or on very significant grants we are making in the field of cancer research. But these are some exceptions. The rule, when talking about a specific industry, is to think about that industry and about what its self-interest might be. Obviously, we are extremely interested in well-considered technical research projects, and we know that our own sophisticated internal research efforts cannot begin to touch on every technical area important to our business. The academic community can -- and increasingly should -- supplement industrial research efforts in a variety of subject areas. We are open to such proposals.

There are some potential problems which must be addressed in any discussion of cooperative research, but I doubt that any of these are insurmountable. It is certainly possible for the business and the academic communities to work together and overcome any barriers, while protecting the interests of all sides, and obeying the law in the process.

In addition to providing financial support, industry can make other significant contributions to academic endeavors. Industry can, in many cases, become more open about its own research efforts. With the exception of sensitive, proprietary work, I am certain that many results can be shared willingly. At General Motors, for example, our scientists and engineers regularly publish the results of many of their completed and continuing projects.

I am aware of the difficulty of keeping abreast of all the work going on today. I strongly recommend that those who are interested in industrial research developments establish and maintain personal relationships with their industrial counterparts -- the people in industry responsible for R & D work. If I were to put my finger on the single thing that would best facilitate our relationships, it is this one-to-one personal trust between two individuals working in the same field. This is by far the most productive way to transfer information and technology back and forth, far better than published reports.

Many companies in many industries have expressed interest in some mutually agreeable form of personnel exchange. Under the proper circumstances, General Motors would welcome an opportunity to investigate the merits of loaning executives with specialized knowledge and experience to universities and colleges. We have done some of that; more would be beneficial. For the same mutual benefit we would like to explore the possibility of faculty members taking sabbaticals as protempore members of GM staffs and divisions. Again, we have done a little of this; we think it has been productive, and we believe that much more could be done. There may be some problems for business, and maybe for the universities as well, but we think those problems can be surmounted. The benefits both to industry and to the academic community are well worth this effort, and will enable both parties to find a way around most obstacles.

Additionally, we think we would like to extend the benefits of this idea of sabbaticals to high-potential students. General Motors has been heavily involved in cooperative education through the General Motors Institute for almost fifty years; we graduated our first four-year engineers in 1932. This longevity is good testimony to the value we place on the Institute. Many of our best people come to us through a program which combines classroom and lab work and on-the-job study. There are so few drawbacks to the program involving the work-study idea that I am confident many additional companies will be willing to try this more efficient alternative. I hope the academic community will be equally willing to increase its efforts in cooperative education as an effective way to improve the relationship between the school and the workplace and to expedite the transfer of technology.

Second to cooperative programs, we believe that a summer or two working in industry provides the best preparation for science and engineering students. While I'll confine my remarks here to science and engineering, cooperative education and on-the-job study probably work as well in other areas. The student who works in industry for the summer learns a little bit about the world of work and the free enterprise system, and what will be expected of him there. He or she begins early to make the connection between what the university can and should be doing, and what in the industrial world needs to be done. We have found that people with this experience have a real advantage when they begin their full-time careers. I would encourage academic counselors and placement officials to establish and maintain relationships with industry representatives, and to be sure that qualified students are aware of the opportunities in this area. In general, the industrial community is very responsive to the needs of the academic community, as long as those needs are known and understood.

I would like to suggest some further ways in which the academic community can gear its efforts to meet industry's needs. Our schools of science and engineering can provide some of the highest quality, most promising research obtainable anywhere, whether it is directed contractual research or investigation undertaken in more general subject matters. The resulting advances in knowledge can play a most significant role in our nation's continued technological development. Once again, the optimum results can be achieved only through a close working relationship. Researchers should get to know the people in industry interested in their specializations, and work to tailor research efforts to their specific and particular needs. Above all, researchers should develop the ability to transfer the results of experimental work from the laboratory to the industrial world.

I have said to GM employees a hundred times, that unless something happens in one of our operating divisions where we actually make something as a result of research or innovation, then our Manufacturing Development laboratories have not done anything either for General Motors or for mankind. Unless somebody picks up an idea, and from it makes a better product or initiates a new process, we have not really accomplished very much. The transfer of technology is probably the most critical step. At General Motors, for example, we have hundreds of highly skilled people in our Manufacturing Development operation, and hundreds or perhaps thousands more in our operating divisions, whose mission is to investigate advanced tools, machines and processes which will enable us to manufacture better, higher-quality products. But the biggest barrier we face regarding the quality of our products is not in R & D. It is the obstacle of the manufacturing organism, perhaps embodied in the manufacturing supervisor who is unwilling to depart from customary procedures and take a calculated risk involving either unique materials or unique processes. We all know that this is exactly what he has to do; so how do we get him to do it?

Let me illustrate the problem. At General Motors, we will say, several years in advance, that at 8:05 on September 18 in Arlington, Texas, a car body will come from the plant, marry up with a chassis, and we will have a brand new car. The average car has about 16,000 parts; all 16,000 of those parts will come together and make a perfect car. If you, as manufacturing supervisor, had to be sure that this car appeared on schedule, you might go just a bit overboard to make sure that you used nothing but absolutely proven technology. You wouldn't want to be the one person who stopped us from making that car on that day. Consequently, when you approach manufacturing people with the idea of new technology, they are something less than enchanted. Much of the productivity problem is concerned with this last step: how do we convince this hardnosed guy who has to make something happen that he ought to go about it differently?

Applied research is usually thought to be a three-step process. We determine a need, develop or advance the relevant body of knowledge, and then follow through to successful application. It is the neglect of that follow-through step that makes it difficult to judge the value of the whole process. If we do not make the final step, the entire process is in question.

The importance of the research contributions of colleges and universities is surpassed only by the importance of the products they supply every year -- the graduates trained and equipped to take on meaningful positions in industry. I'll offer a slightly facetious sketch of the graduate we need. He or she has earned a bachelor's degree in science or engineering while working in a university-industry cooperative education program. After receiving that degree, obviously standing number one in the class, the graduate worked in industry for a few years, then returned to school for an MBA, and now has one foot in science and one foot in business. Our ideal graduate, then, is well-versed in economics, finance and international studies, and speaks several foreign languages. He or she has continued to develop experience and skill in a particular technological area as well. In addition to education and practical experience, the applicant offers a thorough understanding of the corporate process, a variety of ideas about how to improve our operations and, perhaps most importantly, the knowledge and skill to sell those ideas to our managers. We have never really had a graduate like that, but we would be a world-beater if we found one.

Perhaps from the standpoint of an educator the last of those attributes, the ability to sell ideas, may be the most difficult to instill. But it is also one of the most valuable abilities in the repertoire of any top business person. At every level, we must encourage our students and our employees to develop the ability to convince others of the value of a different approach or a different method or a different product. New direction entails some degree of measured risk. It is our job as educators and industrial managers to evaluate risk in the light of the potential rewards. But to do so we have to develop in young people the ability to present those risks and rewards in a reasoned, convincing manner. I am talking about probabilities, quantitative measurements of the potential risks and rewards.

The shelves of our libraries and our laboratories are filled with projects which have not yet been sold. We have the merchandise on the shelves and we need to move it. In an age when progress depends on the practical application of innovative ideas, these shelves represent little more than wasted national resources. In view of the increase of foreign manufactured products sold in the United States and the economic loss to the U.S. which results from this relatively recent trend, we can little afford to waste any of our potential resources.

The growing dominance of foreign products is readily seen throughout our economy. In one sense all competition, whether foreign or domestic, is necessary and healthy -- but only when that competition is both free and fair. Here I offer my sixth point. I am not an advocate, nor is General Motors, of protectionist measures designed, for example, to limit the import of Japanese automobiles. But American manufacturers face a bewildering variety of restrictions if they want to market automobiles in Japan. This disparity should not exist, and we hope that all governments will take a close look at their export policies and their import restrictions.

The success of Japanese manufacturers in the United States points out a startling facet of the state of U.S. business today. Irrespective of product, neither Japan nor any other nation possesses any technology not available in the United States. What the successful foreign manufacturers do is visit the U.S., notebooks and cameras in hand, and take home the best examples of our product design and manufacturing technology. In many cases they have improved on the manufacturing process to the extent that many American firms have serious cause for concern. When we carefully study the Japanese-built automobile, for instance, we find there is not a single item of technology, nor a single innovation, that is not available in the U.S. We are not foreclosed from doing what they do, not by technology certainly, not by invention, not by innovation.

All of the technology used to control automobile emissions, all of the technology permitting increased fuel economy and safety, all of the design and engineering techniques, were readily available to the Japanese tourist businessman with his notebook and his camera right here in this country. Given that, it is reasonable to ask why so many cars sold in the U.S. last year were Japanese-built. There are several reasons. One reason is the ability of the Japanese automobile manufacturer, in many cases, to outmanufacture some domestic operations. Simply put, while there is no technology gap between the United States and Japan, there is some evidence of a manufacturing practice gap.

I want to make a parochial point about manufacturing. If I were asked to name the most significant area of concern to American industry over the next decade, the answer would be the level of basic manufacturing processes and skills; specifically, the expertise of the highly skilled manufacturing engineer. I think that we occasionally forget that this area is vital to the needs of the country. Unfortunately, the manufacturing engineer has for too long been burdened with the stereotype of the grease-under-the-fingernails, bull-of-the-woods type, whose principal function was to make sure the production lines ran at maximum speed and the machine uptime was maximized. Few images are further out of date than this one. The manufacturing engineer we need so desperately in the coming years will have a university degree in a recognized, specialized manufacturing engineering program. There must be four- or five- or six-year university programs aimed squarely at manufacturing engineering, as distinguished from mechanical engineering, electrical engineering or other specialties. There are very few of these programs, and those that exist need to be better. This same person will have an advanced degree in business, be thoroughly familiar with current and future manufacturing processes, and have the ability to implement the technological developments necessary to meet our continually changing manufacturing requirements. If the manufacturing engineer I described sounds a little bit like the optimum job applicant I talked about earlier, it's intentional. The valuable manufacturing engineer today must possess all of that education, skill, experience, and judgement if United States industry is to meet successfully the challenges of this decade and the years to come. Our industry, and every industry, will require this kind of contribution if we are to remain competitive here and abroad.

Questions

Waldo Rall: Where do the Japanese get their trained manufacturing engineers?

Thomas O. Mathues: I don't really know; does anyone else have an answer?

Speaker from audience: There is a strong liaison in Japan between universities and industry, and a particular manufacturing engineering professor would have a direct line to a number of companies. He would recommend to these companies the types of students that he knows they are seeking.

Mr. Rall: The Japanese have the "employment for life" philosophy, and therefore invest a lot more training in their own employees than any counterpart companies in this country do. All Japanese employees go back to school in their companies at least one month of every year.

Mr. Mathues: Is it your suggestion that unless we do the same we cannot catch up to them? Do you think that we should employ our personnel for life?

Speaker not identified: No, there is a lot more in-class training in manufacturing engineering. If you cannot get it from the university you can do it yourself. It costs you money, but it's possible to get a payback.

Questioner not identified: Does GMI have a course of curriculum in manufacturing engineering?

Mr. Mathues: Yes, we do. I think MIT also has one.

C. W. Dean: Most schools of engineering produce hordes of industrial engineers, who could easily be what you call manufacturing engineers if they were ever in a position to do more than conduct time-and-motion studies. Simply establishing standards for piecework rates and so forth is very pedestrian, but a large number of these people spend their whole careers doing this type of thing.

Mr. Mathues: You are perfectly right. Industrial engineering training is an awfully good springboard, but we are talking about going much farther than that.

Dwight Bauman: I would like to address the manufacturing engineer problem. When industrial recruiters come to see us they are looking for seventy-five B.S.'s, eighty Ph.D.'s, so many master's; there is no product differentiation. If you would specify more carefully what you want, and put a price differential on it, I suspect you might get better results. But at the present time you operate on a single parameter system. You send the recruiters out, and get back a lot of raw material. What happens to the students who are hired, we do not know. But industry does not feed back into our system and tell us what it wants. If you bought steel on a single parameter system, you would soon go broke.

Mr. Mathues: Much of what you say is exactly the case. On the other hand, General Motors, like a large university, is far from monolithic. We do what you say, but also what you say we should do.

Dr. Bauman: Let me tell you about my experience with Japanese industry. I was working on memory systems while on the faculty at MIT, and a student came to see me with a full curriculum to get involved in memory systems. He was planning to return to Toshiba, and the courses he wanted to take plus the projects he wanted to do left him one course short of a master's degree at MIT. I tried to convince him that he should take his extra course and get the degree. But he felt he didn't need the master's degree; he had agreed with Toshiba to take these courses, work with this professor, do this job, and come back to the company. Now, if you get your employees to the point where they are this valuable to the company, then I suspect you will have your problems solved.

Mr. Mathues: The solution would be on the way, anyway.

BIOGRAPHICAL NOTE

Mr. Thomas O. Mathues has been vice president in charge of the Manufacturing Staff of General Motors since 1978. Six corporate sections report to Mr. Mathues: Manufacturing Development, Real Estate and Property Management, GM Photographic, Energy Management and Plant Engineering, Manufacturing Engineering, and Air Transport.

Mr. Mathues joined GM in 1940 as an Inland Division cooperative student at General Motors Institute. He attended Grove City College and the University of Illinois while serving with the U.S. Navy during World War II. Part of his naval service was spent as an instructor in electronics. In 1976, Mr. Mathues attended the 73rd Advanced Management Program at the Harvard Business School.

Mr. Mathues returned to Inland in 1946 as a junior engineer. He was graduated from GMI in 1947 with a B.S. in mechanical engineering and the following year was named project engineer. In 1950, he was made supervisor of engineering physical testing and in 1952 became director of laboratories.

Mr. Mathues was promoted to chief engineer in 1956, to director of sales and engineering in 1962, and on July 1, 1966, was named general manager of the Inland Division, the post he held until his election as a vice president of the Corporation.

Mr. Mathues is a registered professional engineer in Ohio. He is a member of the University of Dayton Board of Trustees, the General Motors Institute Board of Regents and Tau Beta Pi.

Cooperative Research: A Student's View

Mr. Timothy G. Gutowski[1]
Department of Mechanical Engineering, MIT

The MIT-Industry Polymer Processing Program is currently sponsored by nine companies, and includes five professors and twenty-four students working on twenty-one projects. Research topics range from the friction and wear of polymers, solvent separation and moisture content measurement, to nondestructive evaluation. Started in 1973 with seed money from the NSF, the program has developed methods of project selection and review and program review.

The key benefits of the program to students are financial stability for projects, close interaction with industry, development of communication skills, and increased job opportunities. In return, students bring to the program an unbiased and unconventional approach to research projects; they should not be considered in competition with consultants.

Students experience several conflicts within the program. Often the desire to publish research results is at odds with industry's proprietary standards, and students are often at the focus of the dispute. Problems of disclosure may arise during students' job interviews. Most of these problems can be solved if students are invested in the project, are included in the patent submission, and are aware of the implications of public disclosure on patent rights.

In presenting a student's view of cooperative research, in particular a view of the MIT-Industry Polymer Processing Program, I would like to discuss four different areas: first, the program itself; and then, 1) how students benefit from it, 2) what students bring to the program, and finally, 3) a little about the conflicts that students experience in the cooperative research environment.

The MIT-Industry Polymer Processing Program

The MIT-Industry Polymer Processing Program is made up of MIT faculty and students, as well as technical and administrative assistants, and industrial sponsors including those members who sit on the Industrial Advisory Council. The director and prime mover behind the Polymer Processing Program is Nam P. Suh, Professor of Mechanical Engineering at MIT. Presently we also have an associate director, Professor Lewis Erwin, who is, by the way, a former student in the program.

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[1] Since this talk, Timothy G. Gutowski has received his Ph.D., has joined the faculty at MIT, and is now Assistant Director of the MIT-Industry Polymer Processing Program.

To aid in the administration of the program, our research projects are organized under the group leader system; older graduate students, usually Ph.D. candidates, are available to help and direct the younger students in their research. In almost all cases, research projects lead to student theses, and of course all of these are under the supervision of some faculty member. Students interact with faculty members (both those on their thesis committee and other faculty advisors) and with their particular project's industrial representative.

The program is sponsored by nine different companies: AMP, Kodak, GM, Goodyear, Instrumentation Laboratory, ITT, Lord, Rogers, and Xerox, which vary somewhat in size.[2] The program started with somewhere between one to three companies -- depending on what you define as its beginning -- and at one time had twelve sponsoring companies. The program operates on an annual budget of more than a half million dollars. The individual fee a company must pay varies with the volume of plastics business that they conduct; this can range from twenty to one hundred thousand dollars per year. This money supports five part-time professors from the mechanical, electrical and chemical engineering departments. This diversity in advisors is also evident in the breakdown of students: currently there are sixteen in mechanical engineering, two in electrical engineering, and six in chemical engineering. Eleven are Ph.D. candidates, ten masters, and three bachelors. These students work on a variety of research projects, including Drying of Polymers, Molding of Ceramics, Interpenetrating Polymer Networks, Extrusion Rheology, Friction and Wear of Polymers, Structure-Property Relations of Polystyrene, Tough Composites, Reinforced Reaction Injection Molding, Fiber Breakage, Processing of BMC, Separation of Hexane from Polybutadiene, Nondestructive Evaluation, Electrically Conductive Composites, Processing of Composites, Sequential Forming of Plastic Parts, and Intelligent Injection Molding; the diversity of projects is evident. These projects vary in length, depending on the student working on the project and the research goal, but in general they are about a year and a half to two years in duration. Of course, very fruitful areas are continued by new students.

To solve problems that emerge during their research, students must call on a variety of academic disciplines. I asked the students in the Polymer Processing Program to list the three academic disciplines they relied upon most in solving problems encountered in research. Their responses ranged from Heat Transfer to Organic Chemistry to Solid States Physics; the disciplines used most often vary widely. If you were to make a plot of research projects versus academic disciplines you would obtain broad scatter with very little correlation between the two. By contrast, in laboratories that are organized around particular academic disciplines, a stratification along that individual academic topic would emerge.

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[2] As of publication, the program has ten member companies. Boeing, DuPont, and Martin-Marietta have joined the program and Goodyear and Rogers are no longer members.

Because of this interdisciplinary atmosphere, students in our laboratory get a unique education. They become problem oriented rather than analysis oriented. Most people, I think, tend to try to solve problems with familiar solutions, while in our program students are exposed to many approaches to problem solving, and learn to find their way in unknown areas. I would speculate that these are very valuable lessons for encouraging innovation in industrial problem solving.

Our projects are selected from lists submitted by the industrial sponsors. These are jointly reviewed by the sponsors and director and other interested faculty and students, particularly those looking for research projects. During the course of the review, stated problems may be redefined. For example, it may be that a sponsor makes fiber reinforced injection molding parts. During the mold-filling operation, fibers are oriented in a direction perpendicular to stresses that the part will experience during use, so some of the parts eventually fail. The sponsor's original problem statement may be "How can we control fiber orientation?" After some discussion this statement might develop into "We want to make lightweight, inexpensive, strong parts."

Each potential project must fit certain criteria, which address both academic and commercial considerations. The project must 1) fit in with the industrial member's current undertakings, 2) lead to better (i.e., more productive) ways of accomplishing existing processes, 3) have potential for achieving significant results, 4) be of educational value (i.e., good thesis material), 5) offer an intellectual challenge, and 6) benefit the collective sponsors.

In addition to these six positive requirements, it is necessary to avoid 7) irrational process technologies, 8) refinements on obsolete technologies, 9) working on problems that really do not exist, and 10) working on projects the results of which would be obsolete by the time work was completed.

Once the project is selected the students write a formal "Project Documentation," a brief summary of plans and projected schedules for approaching the problem, which is distributed among the sponsors so that they can keep track of the various projects undertaken.

There are several mechanisms for reviewing projects once they begin. The most important is the quarterly review meeting, which takes place every three months and lasts about two days. At these meetings all students must give an oral presentation of their research results, followed by a critique by the industrial sponsor and an open discussion. These meetings provide an excellent opportunity for students to interact with the industrial members, both formally and informally. In addition, we prepare an overall summary of the different research projects and their recent progress. I should mention that about once a year meetings are held at member companies, giving us the opportunity for plant and lab tours. These visits have been rewarding not only to the students, but to the industrial representatives as well.

In addition to industrial input and review through the quarterly meeting, one individual from industry acts as a student's primary contact on each particular project. This is the industrial representative who, in addition to making technical comments, may help students obtain material or gain access to some piece of equipment. For most students, these contacts are invaluable. The industrial member offers motivation and encouragement to the student while monitoring the direction and progress of the project. There are also various other meetings between faculty and students, and meetings with individual firms in between the regularly scheduled reviews.

The overall program review is conducted through two very different mechanisms. The first is the Industrial Advisory Council, or IAC, which meets four times yearly to advise the program director on policy matters. It is made up of high level management people, with one representative from each of the sponsoring companies. In addition, a full-time student representative sits in on these meetings. These councils fill a top-level review function analogous to that of a corporate board of directors. The members of the council act as champions for the program within their own companies; they must justify the program fee, and search for ways to apply the research results to their companies' operations.

To serve a completely different review function, several NSF-sponsored reports have been written in evaluation of the program. The most comprehensive of these, by Richard Kutta and Robert Lund, was written after the program's first five years, and is the source for much of my information here.

One of the most tangible results of the Polymer Processing Program is hardware. Since we deal in processes and materials, often the final result of a project is a specific physical device. These devices or processes are usually protected by patents. To date, about seven patents have been awarded to us, and about nine are currently being processed. The patents we hold are for a fiber reinforced composite of high fracture toughness, an electrostatic method for mixing particles, a new, simpler and less expensive type of reaction injection molding machine, an electro-mechanical mixing device, a viscous liquid mixing device, a rapid thermoplastic forming process, and a low shear work plastics melting device. There is a special patent agreement between MIT and the industrial firms. Briefly stated, MIT holds the patents, but the industrial sponsors have a royalty-free, nonexclusive, irrevocable license to use them. In addition, those who were sponsors at the time of invention receive a percentage of the royalties.

The program also results in ideas, ranging from highly formal ideas embodied in theses and published articles, to more informal ideas emerging from discussions or unsuccessful experiments. Some of our sponsors tell us that such ideas have helped shape their own laboratory planning, directing them toward some objective or away from what has proven unsuccessful. Many sponsors have mentioned repeatedly that they benefit from the accessibility to other industrial personnel that the program provides.

Finally, an important output of the program is its graduates. In the past, Ph.D. graduates generally went on to academic jobs, and masters graduates to industrial jobs (about half going to the member firms). But this trend seems to be changing; our two most recent Ph.D. graduates are entering industry, and more Ph.D. candidates are now indicating interest in industry.

How Students Benefit From Cooperative Research

That, in essence, is the program; now, how do students benefit from it? First, they gain financial stability. The students are aware that a program of this size allows both financial stability and continuity in research projects. In the NSF report I mentioned earlier, students ranked this support as a primary reason for their involvement in the Polymer Processing Program. Financial stability continues to attract new students to the program.

Perhaps one of the most rewarding aspects of the program is the close interaction between students and industry. The students work with high-level management, in a proximity which would not otherwise occur until many years into a career. This exposure gives students insight into management thinking, especially the necessity for management to justify the cost of the program. Students also gain access to existing knowledge, equipment and materials in industry; we have visited many industry centers to observe existing manufacturing operations and laboratories. In fact, since I have been with the program I have visited five different companies, some several times. Students benefit most from the industrial interest in their projects, an interest which motivates them and gives students a sense of the importance of their work.

Students also are able to develop communication skills; along with the four regularly scheduled meetings each year, there are many opportunities for students to present their research results orally. This is rewarding not only to the students, but to the faculty and sponsors, who watch students improve over the course of the program.

Finally, some of the prime benefits of the program are the employment opportunities it provides. First, the industrial exposure that students gain makes them quite attractive to industry. Secondly, because of their close contact with industry, students can evaluate companies while the companies are evaluating them. Many of our students receive job offers from companies, which in itself is gratifying, and acts to assure students that their career choice is wise.

I would sum up then by saying that a student's experience at the MIT-Industry Polymer Processing Program is shaped by three crucial factors: it is a cooperative venture, it is here at MIT, and it is directed by Professor Nam Suh. At this point, I would like to comment that Professor Suh creates a particularly enriching research and educational environment here at MIT, which provides students with a variety of projects and exposure to many different academic disciplines. The enormous trust that Professor Suh shows in his students encourages them to try things they might not otherwise attempt; this confidence and trust is essential, I believe, to cooperative research and the innovation process.

What Students Bring To Cooperative Research

It is important, I think, to recognize what students bring to cooperative research. Some industrial people may think of cooperative research as an alternative to other types of research efforts, for example, research conducted in industrial laboratories or perhaps through consultants. Students are not consultants, although they learn quite a bit and are more professional by the time they leave the program. First of all, students are cheaper than consultants. Much cheaper. Secondly, they bring to a project not the thorough nuts-and-bolts knowledge of the experienced professional, but a fresh, undogmatic, unbiased viewpoint. Most of our projects begin with problem definition and physical reasoning. There are no stupid questions, and no easy answers like "we always do it that way." For example, in the case of a problem where the output rate and the heating rate are coupled functions in a single screw plasticating extruder, a student without a moment's hesitation will throw out the single screw plasticating extruder and try to invent his or her own extruder. Industry professionals might cringe when they find a hundred single screw plasticating extruders on the inventory list, but this is an example of the educational dynamic that takes place between students and industry. A student's fresh and unbiased approach, when coupled with proper leadership, can bring forth new inventive solutions to problems. Because of such attitudes, I think students are particularly well-suited to high risk high gain projects.

Conflicts That Students Experience In The Cooperative Research Environment

There are several areas in a cooperative research program where academic interests and industrial interests conflict. Students are often caught in the midst of these conflicts. For example, the student's desire to publish research results is often at odds with industry's desire for confidentiality and lead time advantage. This obstacle is frequently overcome by the natural delays associated with the publication cycle. Clearly, however, some compromise between the two desires must be established and understood by the two parties. A second conflict occurs when a student needs to discuss his or her research at a job interview prior to filing for a patent. There is no simple solution to this problem, but this situation is not unique to cooperative research. All of our students who work on patentable projects are co-inventors, and consequently have a vested interest in the patent right issue, so they make it their business to understand the rules and to comply with them. A third example is when a student may want to deal with proprietary material in a publication, which can cause difficulties for industry. Again, this is not an easy problem to solve. One possibility is to run dual experiments using a similar but nonproprietary material; alternatively (and this is often done) the proprietary material may be handled with a certain deliberate vagueness in the publication.

In closing I would like to say that from the student's point of view the Polymer Processing Program is an enormous success. The program addresses many of the immediate needs and immediate issues of the students, provides financial support, supplies thesis material, and makes students attractive in the job market. I would speculate that what distinguishes the education received in the Polymer Processing Program from other types of education is that the student will realize continuing rewards, especially in his or her ability to handle new problems in a creative and innovative fashion.

Questions

Richard Alben: A previous speaker raised the issue of academic freedom, and the problems that this type of program might bring in that regard. Do you think that this program fosters or hinders academic freedom?

Timothy G Gutowski: I think it is clear to all students that compromises, usually in the scheduling of a publication, have to be made. Other than

that there is not, as far as I am aware, any evidence that students feel a problem in this area.

Wilbur Meier: Will you contrast your experience with that of your student colleagues working on government-sponsored research?

Mr. Gutowski: I can give you one obvious difference: I see the students in our program getting many job offers.

Mr. Meier: I was thinking more of issues like the significance of your research results and the academic quality of the program.

Mr. Gutowski: Well, I commented on the benefits in the diversity of academic disciplines that students call upon to solve their problems. I think that there are various ways to approach a research project. I have spoken about the way we approach problems here, and it happens to be new for me and very rewarding. I am sure you can give examples of very fine people who have followed different academic paths; I happen to think that this is a rewarding one. It is worth trying, and it may lead to a slightly different orientation on the part of the student. Perhaps someone who stays in one narrow academic line may end up by applying its principles very well, but only in that narrow academic line. A person who is aware of different possible solutions and different disciplines may call upon these, and be more inventive in solving problems.

Speaker not identified: I perceive by your answer that you consider your background to be much broader than it would have been had you worked within a more conventional research program.

Mr. Gutowski: Well, I guess I would have to experience the conventional program to answer that -- but yes, I do think my background is broader. Polymer processing is not, at least right now, an academic discipline; our laboratory is not like a fluid mechanics laboratory, or a heat transfer laboratory, or an acoustics laboratory. One of the first things that surprised and bewildered me when I first came to the Laboratory were all of the different disciplines that were called upon to solve problems.

Marvin Goldberger: Does what happens in the Polymer Processing Program constitute something which is greater than the sum of the parts that go into it? Or, to restate the question, would those people now involved in this program be carrying out more or less the same research activities had you not put the mantle of "program" over them? I want to leave aside the question that this may be a very effective way to channel funds. Is there really a synergistic effect in bringing this group together?

Mr. Gutowski: I can answer the question from the student's point of view. I think there is a synergistic effect. I am not aware of the subtle difference to which you allude; if we took away the program, would my experience differ? I don't know. Certain window dressings could be rearranged and the experience would be equally rewarding.

Dr. Goldberger: Let me try to clarify the question; I am not trying to be subtle. There is a group of faculty carrying out certain kinds of research in this area, who have been put together in what is called the Polymer Processing Program. Is the product of that research significantly different from what that same group of faculty would have produced had they not called themselves a program?

Nam P. Suh: I would like to respond to this question.

The reasons we started the Polymer Processing Program ought first to be looked at. Polymer processing is an area that I did not specialize in -- I did not get my doctorate in that area, and in fact, I did not take a single course in the subject when I was at the university. When I came to MIT, I realized that we spent an awful lot of time teaching our students about metal processing, and the fact that we process more plastics than metal did not make any difference in the way we taught. So we wanted to balance that. We said, we have got to teach our students polymer engineering versus polymer science. The question was, how do you do that?

Secondly, when I came back to MIT after being away for ten years, I realized that we were doing a pretty poor job of teaching the creative aspects of engineering. How do you teach students how to synthesize things? We tried to address these questions, and I thought the best way to do it was to have industrial input. A year later, the NSF came by with this experimental R & D incentives program, and we got started.

As far as questions concerning the quality of thesis and research work, let me give you some examples of what we go through. We tackle all sorts of problems. For example, one of our member companies, IL, came to us and said, "We use an awful lot of plastics in our blood gas analysis. Blood goes through these instruments and messes them up, and we have to clean them. What can you do about it?" I assigned the subject to the students. None of us on the staff had any prior experience in this. We looked at the literature on the subject, and found that no one really knew what they were talking about. The question was, if you have a blood plasma, why do those protein molecules approach the surface? We talked about Brownian motion, and we looked at all of the surface tension aspects, and so forth. If you put the relevant data together, the published opinions and published results are not really consistent with what we know about what is happening. So our students started scratching their heads and I scratched mine, and we came out with a hypothesis. It was based on the diffusion of protons into these plastics and solids which tend to create charge imbalance within the fluid, which in turn attracts proteins to the surface. Based on this hypothesis, we predicted that materials with a high cohesive energy density would be those with the least amount of absorption on the surface. Our experiments proved this to be accurate, which opened up a whole can of worms.

Taking on a problem like that and asking the rational questions are all I want our students to do: ask intelligent questions and see what the conclusions are. I think the quality of our theses is very high. I do not care how many fields you work in -- in fact, I work in many different areas; my only rule is that no matter which area you want to get into, you have to be as good as the top man in that business. Otherwise, do not go into it.

The argument that we are in many different fields and therefore our quality of work should be inferior to others doesn't make sense at an institution like MIT. In our doctoral examination, the master's thesis carries twenty points out of 100. We evaluate the master's theses very carefully. It turns out (and many of my students may not know this) that most of our students entering the Polymer Processing Program score almost the full twenty. These exams are not given by me, but by many faculty members. It says something about the quality of our theses.

Our publication record is very good. Our students have a very long list of publications, as well as patents, before they leave. As far as the issue of academic freedom, you have to look at what we do here in terms of the goals of the institution. If we say that the institutional goals of MIT are education, research and service to the public, we have to see whether or not any one of these is compromised in any way, or whether we are enhancing them. I say we are enhancing them. And therefore, I say there is academic freedom within our program. We do agree to delay our publications for six months -- but wouldn't you do that if there was a patent to come out in your name, and you wanted to protect your rights? It is not really a major compromise.

Instead of talking about the nitty-gritty, I think we have to look at what our goals are, and how we are going to get at them.

BIOGRAPHICAL NOTE

Mr. Timothy G. Gutowski has recently received his Ph.D. in mechanical engineering at the Massachusetts Institute of Technology, and has joined the faculty there. He has been in the MIT-Industry Polymer Processing Program for the last two and one-half years, and presently is assistant director. Previously [illegible]d a B.S. in mathematics from the University of

Wisconsin in 1967 and an M.S. in theoretical and applied mechanics from the University of Illinois.

Mr. Gutowski held several professional positions between 1968 and his return to graduate school in 1977. These included working for Wiss, Janney, Elstner and Associates, a structures and dynamics consulting firm in Northbrook, Illinois. He also taught mechanical engineering subjects to university students while in Ecuador with the Peace Corps, and he was a senior consultant in noise and vibration with Bolt, Beranek and Newman, Inc. in Cambridge, Massachusetts.

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Factors Affecting Research and Development Performance

Professor Edward B. Roberts
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Fifteen years of research on corporate technological innovation indicates that effective staffing, structure and strategy are the elements of successful R & D. Staffing *must insure that five critical functions are fulfilled: generating ideas, entrepreneuring or championing, project managing, gatekeeping, and sponsoring or coaching. "Gatekeeping" refers to facilitating technical information flow and market and manufacturing inputs.* Structure *must both assure proper data flow into R & D and channel research results to marketing and manufacturing downstream. Users who generate innovations can skip over some innovation process stages, and the use of these innovations may necessitate structural adaptations in the R & D performing organization.* Strategic planning *methods must be used in the technical areas of the corporation, as well as in finance and marketing. Competitive technical analyses are a starting point for technology planning; corporations need to experiment with technology measurement and forecasting as well.*

I would like to begin with a story about effective management of research and development.

The new vice president of R & D came into his job on the first day, and bid his predecessor a fond farewell. As the predecessor was going out the door, the new head of R & D said, "Oh, if you have a minute, I would like to learn from you all there is to know about managing this organization effectively." The predecessor said, "Well, I have given careful thought to this and in your bottom right-hand drawer you will find three envelopes that I've prepared for you. But do not go to these envelopes until you really are in trouble." The new head of R & D thanked him very much and went on about his job. Well, six months into the job he was really having problems. The place was a mess and there were great difficulties in running the organization. He did not know what to do. Then he remembered the envelopes. He pulled open the bottom drawer, ripped open the top envelope, pulled out the slip, and it said, "Blame your predecessor." He thought, "Oh, what an amazing suggestion. It is not really ethical but my predecessor suggested it, so why not?" And he went around bad-mouthing his predecessor and indicating that everything going wrong was the fault of the former head of R & D. And sure enough, everything quieted down and things were back in order. But six months later, he had crises. He had problems. There were great difficulties. He was trying to figure out what to do when he remembered the envelopes. He pulled out the second envelope, ripped it open, and the slip said, "Reorganize!" He said, "Reorganize? Well, that is a very creative suggestion." And in the process of reorganizing, he created so much turmoil and confusion that everybody forgot the original problems, and things settled down. Well, another year went by and everything was OK. Then once again he was really in trouble and trying to figure out what to do, when he remembered the envelopes. He pulled out the bottom drawer, ripped open the last envelope, pulled out the slip, and it said, "Prepare three envelopes."

That is one way to handle R & D management, but I would like to offer a different story line. This line is also simple, because it says that your only concerns in R & D management are issues of staffing, structure, strategy and systems. There are a few items under each of these headings that, as research studies carried out at MIT and elsewhere over the past fifteen years indicate, are the keys to effective management of research and development. My topics are for the most part well-documented, and I am sure many are familiar with the articles and studies relating to this subject that have come out of the MIT Technology Management Group over the past several years.

There are several key issues that influence successful R & D. The first is effective staffing. Two, the structure of the R & D organization must be carefully considered. Three, there is a need for concern with the strategy and planning of R & D, which in my opinion is the principal area of deficiency in R & D management. Finally, there are systems that can be developed and adopted to support the above three areas.

Let us first talk about staffing. Several years ago, I began looking at the research of a number of my academic colleagues at the Sloan School, and looking also at key people in R & D organizations. For a while I concluded that the wonders of modern statistics enabled any researcher to prove his or her point and to develop a publishable article, because it seemed that each of us had found the one key individual in research and development. I had focused my research on entrepreneurs, and there is no question that I demonstrated that the entrepreneur was the *sine qua non* of innovation. My colleague Tom Allen concentrated on the technological gatekeeper, and proved without a shadow of a doubt that this was the person who made the difference between effective and ineffective R & D organizations. Other people had their own key candidates: the creative scientist who came up with ideas, or the program manager who pulled it all together. We found another central person when we looked at industrial attempts to generate new business -- the sponsor. The sponsor is the senior person high in the organization who, like the 'godfather,' affects the careers, the lives and the effectiveness of creative young entrepreneurs and program managers.

Well, all of these different people are intriguing when considered separately, but they had to fit together somehow. As we continued to look at the process of innovation from the viewpoint of staffing considerations, it appeared that we had something significant. There was indeed strong empirical justification to argue that five categorical key roles had to be fulfilled in any technical program in order for that program to advance meaningfully from initial conceptualization to commercialization or implementation. First, creative idea-generators were indeed necessary: people who came up with new points of view not just occasionally, but on a fairly regular basis. But besides those who initiated ideas, there had to be people to take those ideas and run with them, people to carry the ball forward in the organization against the non-riskoriented opposition and the barriers to change that exist in almost every organization. Along with the idea-generator, someone who was entrepreneurial in character was essential.

In looking at the MIT faculty in three departments -- physics, electrical engineering and mechanical engineering -- we were able, with good research results, to demonstrate the significant difference between faculty idea-creators and faculty idea-exploiters. We could demonstrate the characteristics of someone who would come up with an idea, and those of someone who would not only have the idea but move it forward into use. (Incidentally, in reference to industry-university cooperation, we also found that the principal channels for exploitation of MIT-based ideas were long-term consulting relationships with industrial organizations. These were far more effective in getting research results and faculty ideas used than were individual faculty entrepreneurship, new company formation or the other things for which MIT also has justified fame.)

Tom Allen researched the technical gatekeeper, the person who accounts for a disproportionate share of technical communications from the outside world to the inside world. This role is key because most R & D is carried out elsewhere, not within the organization. Companies or universities that suffer from the "not invented here" syndrome are not using the vast world of technical knowledge in their own research and development programs. The gatekeeper who ties that outside world of technical knowledge and advance to the inside technical programs is a critical individual.

Our studies of effective industrial innovation demonstrated that it took more than just a technical gatekeeper; two others were required, whom we called the market gatekeeper and the manufacturing gatekeeper. The market gatekeeper is also an unusual communicator who transmits a disproportionate share of the messages into the R & D organization, but the content of his messages is different. He is not talking about advances in technical knowledge but about the needs of customers, behavior of customers, behavior of competitors, actions of regulatory agencies and organizations. These market-relevant issues must be considered if the technical organization will generate R & D results effectively. The third gatekeeper, the manufacturing gatekeeper, is essential in seeing that what comes out of R & D is not merely laboratory sound devices, but indeed could be manufactured in high volume by workers using available materials. The manufacturing gatekeeper prevents the R & D from being handled exclusively by Ph.D.'s in the laboratory on an experimental procedural basis. He or she bridges the harsh manufacturing production environment and the design and development aspects of R & D.

Beyond this, we found in many organizations clear shortages of people capable of carrying out program management responsibilities. Indeed, in many research laboratories, as opposed to development organizations, the concept of program manager is absent even today. You can find, even in industry, people who identify themselves as principal investigators and not as project managers of research projects. When you ask, "Who's job is it to coordinate the contributions of many people? To worry about advance lead times on materials? To transfer responsibilities from R & D out to the divisions?", the principal investigator may very often reply, "Well, I am not quite sure. I think the boss takes care of that." We found that the skills necessary to coordinate, integrate and subordinate, to enthuse, motivate, supervise and direct technical work -- those abilities inherent in the program manager -- are critical functions of an R & D organization. They are not necessarily carried out well by people who are best at the other functions we identified.

Finally, we identified the role of the sponsor or the coach, the senior person who has been through the mill and is in a position not necessarily to commit resources, but to influence resource shift and direction. The sponsor can encourage junior people in the ideas they pursue, and can encourage his colleague, the boss, to devote attention, time and resources to these junior people. The senior person knows how to write a research proposal that will get funded rather than filed. This sponsor or coach is critical, and the role is best filled by the organization's senior management, if qualified.

These five categorical roles should be represented meaningfully in the staff of the R & D organization. It is not necessary that all be employees of R & D. Some may well be marketing people who are tightly linked to R & D, in a close relationship that allows the functions to be fulfilled within the climate and program of technical activity. It is amazing how many organizations have not considered these roles when thinking about job descriptions, recruitment, measurement and control of people, reward systems, promotion or job and personnel development. These roles are frequently absent yet, in our view, are critical to effective R & D.

One final comment about R & D staffs. In the studies we conducted (and we looked at probably 10,000 technical people) we generally found that seventy to eighty percent of the people in the technical organization filled none of these primary roles. They are instead principally what we call routine technical problem-solvers. What you have in the critical roles is a small minority of key people, twenty or thirty percent of the people in the technical organization who perform these key activities on a regular basis. The rest of the staff, the bulk of them, are not involved in any of these activities, nor do they want to be. When we asked engineers and scientists in questionnaire studies to describe their career development plans, they defined their future careers in the same terms as their present careers. They would like to continue to do routine, but of course challenging, technical problem solving. These seventy to eighty percent don't want to generate or push new ideas; they don't want to get involved in any special communication links or roles; they certainly do not want much management responsibility, and they don't worry about training or encouraging others. They just want to do their own thing. Now, I regard that as a problem, particularly because the overall management systems or organizations tend to be geared to support the sixty to seventy percent routine people as opposed to the twenty to thirty percent who are unique.

The second dimension of an R & D organization, its structure, involves staffing as a central issue. An organizational structure must permit people to work well and effectively. To foster an effective technical operation, this structure must include a number of key elements. First, it has to provide for the 'gatekeeping' mentioned above. You can build organizational structures that stifle gatekeeping and shut off forms of communication, through poor physical setup, for example, or by faulty personnel relationships. Jack Morton, the late vice president of semiconductor research at Bell Labs, wrote a very interesting book called *Organization for Innovation*. In it he discusses Bell Laboratory's two boundary theories of innovation, the notions of the organizational barrier and the physical barrier. If you physically separate technical people by some reasonable distance (and my colleague Tom Allen indicates that the distance is about one hundred feet or less) you will significantly suppress the likelihood of communication between those people. Morton went on to say that if in addition you organizationally separate those people, you create another barrier. If they report to two different vice presidents, for example, no organizational incentive for communication and integration exists.

Morton's bottom line was: if you want to make sure that two groups of people have nothing to do with each other, set up both the physical and the organizational barriers. He discussed the system of structuring at Western Electric and Bell Labs, which allows for only one of the barriers, but not both. Either keep people physically together but organizationally distant, if you want them to interact while protecting their differences, or situate them together organizationally but separate physically, so that their independence is maintained but organizational ties and incentives exist for occasional communication and shared work. The absence of both barriers, however, is counterproductive. If people both report to the same organization and work intimately together, there is a very good likelihood that research will gradually get killed and shifted into development. The pressures are always towards the short-term activity. But if either the physical or the organizational barrier is maintained, it is very likely that research will follow its own course; it will do its own thing in isolation from development and from the organization's commercial needs. It is necessary to create structures that will permit and encourage communication processes across the line.

In particular, close organizational ties are needed between the marketing/sales aspects of the organization and its technical aspects. Some people in industry have, I believe, improperly interpreted 'close ties' to mean domination of R & D by marketing. We find a number of situations in industrial organizations where budgets for research and development are set by marketing-based programs, or by product managers in the marketing division who determine the content of work that shall be carried out within the R & D organization. This is an inappropriate organizational structure, which puts the responsibility for essentially technical decisions in the hands of people who cannot have the appropriate technical information to make those decisions. Even so, I still call for close ties between R & D and marketing. There must be a collaborative undertaking to determine legitimate market needs as well as meaningful technical possibilities and opportunities. This collaboration might be some kind of joint undertaking between the organizations, rather than one being wholly independent of the other or subordinate to the other. Organizational structure can provide incentives, communication and linkages. This is certainly possible in venture situations which naturally bring people together from marketing and technology, but it can also be carried out across the board in R & D.

The special user role in industrial goods innovation should be considered from a structural viewpoint. My colleague Eric von Hippel has been studying the extent to which users are sources of innovation, not just identifiers of needs which someone else then meets, but sources of innovation itself. Von Hippel started with a biased sample; he examined four major fields of scientific instrumentation. He demonstrated that eighty to one hundred percent of the innovation in scientific instrumentation had been generated, implemented and brought to the point of use by users, not by producers of instrumentation. The production of instrumentation followed, rather than led, its full utilization by the scientific community itself. Recognizing the possible bias in the area of his early research, von Hippel went on and studied electronic subassembly manufacturing equipment. And he found the same phenomenon: eighty to one hundred percent of the innovations in that field were developed by users, not by equipment manufacturers. Once the users developed the equipment, implemented it, and began to benefit from it, they frequently approached the manufacturer for multiple replications of their design. Frequently, manufacturers went into business with licenses from initial users who had first developed the equipment.

Von Hippel has been following up this study in a number of other areas. He is able to show not a uniform pattern of user-innovation throughout, but rather that the role of the user as innovator is far more significant than had been previously accounted for. Let me give you an example; it is an example of industry-university cooperation, although there was no formal agreement for the cooperation. IBM's marketing organization set up throughout the U.S. a number of small organizations called Applied Science Centers. (Notice that the *marketing* organization set up *applied science* centers.) One such center, the Cambridge Applied Science Center, was in Technology Square about 100 yards behind the computer building at MIT. It deliberately had a staff of no more than twenty people, whose job was to monitor and interact with innovative sources of change in areas of computer hardware and software. While IBM had a major in-house project to develop its first commercial time-sharing language, the Cambridge Applied Science Center, working with MIT's project MAC, developed its own version of project MAC's time-sharing language, moved it back through marketing channels and out to the field for IBM's first commercial sales of a time-sharing language. This was two years before the "legitimate" in-house project was ready to release its commercial item to the marketplace. Here is an example of an organizational structure that recognized the special user role in coming up with innovation. In this particular case, the university user role was the source for advanced technological change that moved through marketing channels back to the firm and out to the marketplace again in higher volume. There are many other examples like it, which suggest the potential of such creative organizational structures.

A fourth point I would make about organizational structure is that it should be set up to enhance the likelihood of bringing into the firm external sources of technology that are not just user-based, but competitor-based. There is far too restrictive an attitude in the U.S. about bringing on board other people's technology, an attitude much less prevalent in other countries. In particular we have seen the wonderful postwar success of Japanese technological innovation, which is based very heavily on the import of external technology, technology adopted to provide a high-level base for technological advance and then built upon by good quality in-house research and development work. U.S. firms' resistance to bringing in external sources of technology denies available technology to many firms who could benefit significantly from it. If we could get rid of the non-inventive attitude here that claims, "Since we haven't done it, it isn't any good," or "If we haven't done it, we must reinvent it in-house," then external sources of technology could provide a significant supplement to in-house R & D.

Finally, I would recommend that special kinds of organizations be set up -- transfer groups, task forces, venture teams -- whose mission is the transfer of results, and whose principal consideration is not the creation of the R & D, but the movement of R & D to commercial transfer and utilization. Again, many R & D organizations which are effective developers do not effectively reap the benefits of their development. They do not succeed in moving the work outside.

The third area I will discuss briefly is the area of strategy. In looking at a large number of R & D organizations over twenty years of involvement in research and development, I believe without fail that R & D's great managerial lack is in strategic development. Very few research and development organizations have strategies. They have people, programs and knowledge, but they do not have strategies. They lack explicit goals and priorities. R & D people seldom carefully think through a system of planning that will move their organization forward technologically. Now, your corporations would be in a lot of trouble if this were true on the marketing and financial side, but we allow it in technologically-based firms. We keep muddling our way through, and I guess this is possible as long as the competition behaves in the same awkward way. But when a key competitor starts to develop a significant and targeted technology-based strategy, I think a lot of competitive changes will take place within the industry.

I will outline here a number of steps to be taken to lay a base for R & D strategic planning.

1. Identify in technological terms the critical performance dimensions of your product line. How do you measure quality performance in a product? What does quality mean? Usability?

Reliability? Operating cost? Acquisition cost? Serviceability? Adaptability? Conformity with other product lines? What measures the performance characteristics of your product line?

2. Having identified these, assess the competitive profile of competitors' product lines along the same dimensions. Where do you stand? Where will you stand, relative to technological development and competition, in the next generation of products? Are you moving ahead of competition or falling behind? These technological measurements can evaluate your technical program's adequacy, as reflected in your product line relative to your competition's.

3. Estimate market demand for your product -- not only in terms of numbers, as the market research people always tell you, but in terms of market sensitivity to technological dimensions. What is important about your product line? Is energy consumption today a key characteristic, in a way that was not so five years ago? Is size a key issue? Is compatibility a key issue? These questions call for marketing people and technical people to work closely together. To some extent, you need to worry about forecasting technological change, particularly competitors' developments. Engineering and marketing people must pool their resources to track technological developments.

4. Examine your organization's capability. What is that capability? What can you do? Select strategies and develop the organizational plans to implement them. Very few organizations, including the largest, systematically develop technology strategies or the resulting technological plans. I think this is a great mistake.

After worrying about staffing, structure and strategy, you should worry about implementing some system of strategic planning and control that will keep the information flowing and up to date. First, develop competitors' profiles. You should be able to open a file drawer of any major product line, pull out a file and say, "Here are the key performance dimensions of our product line, and this is how we stack up against competition. Here is what we have underway to alter that assessment." Frequently when I ask, "Do you do competitive assessments?", I get pointed to the guy in the corner of the lab. "He is our expert on competitor A." Why? "Because he worked there ten years ago." And when I ask him, "Where is your data base? What decisions are you making from it?", these things are often lacking.

To develop an effective strategic planning and control system:

1. Develop competitors' profiles.

2. Produce marketing forecasts of sensitivity to technical change for your principal areas of concern.

3. Carry out analyses of the staffing and the climate within your organization for performance of the critical roles I described above.

4. Implement a project synopsis system which massages data on your present investments to extract implications from them. Such a system can tell you not just the current status of projects, but what they represent in commitments to the future, in their impact two years, five years, ten years from now. What do present projects indicate about the technology mix being invested in? These synopses give you a system for managing the R & D projects, which is very different from PERT and project control on an individual project.

5. Finally, some key project monitoring is necessary, targeted not to the project manager, but to senior executives within the organization. There are some projects which the CEO should monitor. Key project monitoring will identify the critical projects that make the difference between organizational success and failure, where the double-edged sword of high-level senior management involvement is appropriate.

These are the kinds of considerations I believe are necessary to effective R & D management. Critical staffing -- getting key people along with creative scientists -- is essential. Organizational structure that will assure both inputs from the technology marketplace, users and external sources, and outputs in the transfer of results downstream to the users, is very important. Finally, you need an approach to strategy and a strategy development, which organizations tend to lack, and with it, the systems that make your strategy operational.

If you have done all of this, I am sure you will not need that third envelope.

Questions

Steward Flaschen: Dr. Roberts, in your presentation you briefly mentioned manufacturing. In a factory, the manufacturing or operations manager is often found to be the greatest barrier to new product innovation, or the implementation of new equipment and new processes. He is held responsible by management for producing a number of units per hour, per day or per week. He must get the product out the door by a certain date and at a certain cost, "no matter what." He is generally a conservative person, and normally very reluctant to introduce changes -- things that he did not develop, and certainly things that he does not understand. What did your research show about how one motivates and reaches the manufacturing manager when one is trying to innovate with a step-function improvement on the plant floor?

Edward B. Roberts: There are two things that I would suggest. One, you should have begun worrying about the characteristics of your manufacturing personnel a number of years ago. I do not say that facetiously; I think that it is very important that there be a flow into manufacturing of technically trained people coming out of engineering in particular. If you develop systems of rotation for forward movement into manufacturing, you may well over a period of time begin to change at least the climate of knowledge and awareness. You will not necessarily eradicate the hesitation and conservatism, because if you take a good R & D guy and make him manufacturing manager, he will soon become just as conservative as his predecessor. But you will change the knowledge base.

Having said that, the one thing that we found you can do in the short run is initiate the transfer in the opposite direction. At some point in time appropriately in advance, or when projects are ready for movement, people from manufacturing ought to be moved out of manufacturing into R & D. They ought to become part of the developmental group that is working on problem solving. Manufacturing people should in fact take a key role in at least the final stages -- and by final I may mean the last third to last half of the project -- so that they can feel that their points of view are represented, and that the information about their difficult environment was transferred to the theoretically oriented R & D guys. When the project is ready to move, the first candidate that I would consider to do the moving, without knowing anything about the organization, is the person from manufacturing who earlier had been transferred into the development group. If that person comes back to manufacturing with "his project," there is a very different kind of ownership and a very different acceptance and willingness to trust. When implementing that kind of transfer downstream, I would also accompany it with supporting staff from the rest of the R & D organization.

If anything, there ought to be overkill staffing at the point of transfer, and yet I have found many organizations which say they cannot afford it. But if you look at their track records in effectiveness, it is clear that they cannot afford NOT to do it. The terrific project and the wonderful technical discovery are lost because they are not implemented appropriately; yet when you say you need a key R & D guy for three months in the manufacturing organization to be sure of success, the answer is, "Oh, no, we cannot afford to spare such key people." But this transfer is the kind of thing we found to be most effective.

Two months ago in an issue of *Research Management*, I had an article called "Organizational Approaches to Bridging Innovation Gaps." In the article I list about fifteen different approaches, of which the one I just described is, in my opinion, the most effective, bar none.

BIOGRAPHICAL NOTE

Dr. Edward B. Roberts has received degrees in engineering, management and economics from the Massachusetts Institute of Technology culminating in a Ph.D. in economics in 1962. He presently holds the following positions: Professor of Management, Alfred P. Sloan School of Management, MIT; chairman of its Technology and Health Management Group; and President, Pugh-Roberts Associates, Inc.

Professor Roberts is director of several young technology-based enterprises and serves as a consultant to numerous industrial corporations in the fields of strategic planning, organization design and the management of technical innovation. He has been a member of the Air Force Scientific Advisory Board, the Department of Commerce Technical Advisory Board, and a consultant to the President's Advisory Council on Management Improvement. Dr. Roberts is the author of numerous books and articles on various aspects of management.

The Role of Top Management in Cooperative Research and Innovation

Mr. Donald M. Alstadt
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Technological innovation and the entrepreneurial application of new knowledge obtained through R & D are the primary methods by which the West has achieved its dominant world position and high standard of living. Much of our corporate and government leadership does not understand and is not involved in technological innovation processes, which may be the "Achilles heel" that will jeopardize our future economic growth and national survival.

Science and technology are the most powerful agents for change today, the prime movers in our society. The most significant events occur in the laboratory, and often go unrecognized by the press, the politicians and the corporate executives. Mankind's continued climb in living standards depends on the encouragement of research and the capitalization on its results. However, much of the world's existing technological capability is not being utilized effectively to alleviate economic deficiencies and social distress. Unfortunately, most people in government responsible for the decisions and policies in our society are unaware of this "information lag" -- the discrepancy between what is known and what is practiced.

Heads of corporate R & D often complain that although they have achieved breakthroughs in the laboratory that could rejuvenate their company or industry, the chief executive doesn't understand the significance of the breakthrough, or hasn't the entrepreneurial foresight to further its utilization.

Dramatic changes must occur in the attitudes of government, corporations, universities and society before the innovation process is revitalized and Western technological leadership is re-established. First, government must encourage, by its system of rewards and expectations, corporate leaders to accept innovation as their primary responsibility. Government cannot, through its regulations and paperwork, continue to force corporate management to be primarily legalistic umpires and accounting scorekeepers. Two, corporations and governments must place in key manufacturing positions people with a feel for science, technology and innovation and entrepreneurship. Three, educational programs to refurbish the maturing executive must be enacted in universities and graduate business schools. Four, we and all nations must educate government representatives to an awareness of scientific progress and its technological implications.

I believe that the chief executive officer's role should be a lot more dynamic and a lot more involved than it is in most companies in the United States. Along with examining management's role, I want to discuss the

basic purpose of the corporation, for I think that if we clarify a corporation's function in society, it may stimulate some of our corporate officers and corporate heads to think differently about the innovation process. This, in turn, may influence the selection of corporate officers; we need a somewhat different breed of management than that which we have had in the past.

It is difficult for some in our society to accept the fact that a very necessary aspect of our corporate life is the making of profit, and that an essential aspect of government operation is fiscal responsibility. It is even more difficult, however, for many executives to understand that, in both our domestic economy and in our national and international situation, innovation and not solely the making and managing of money may be the primary and most immediate challenge before our corporate and government institutions. America today will, I believe, retain its industrial, economic and military preeminence only by an appreciation throughout society of the importance of the **R & D** process and its results: technological innovation and its entrepreneurial application. This process, regardless of how it is conducted, is the primary means through which America and the West have achieved and maintained their dominant world position both economically and militarily. Much of our corporate and government leadership does not understand and has never been directly involved in the process of technological innovation. This may be the "Achilles heel" that will jeopardize the future economic growth and indeed the national survival of this country.

Many people have trouble facing the fact that science and technology -- not government manipulation and fiscal and economic action -- are probably the most powerful forces for change in the world today. That a particular change may be valued as good or bad, moral or immoral, does not alter this basic fact.

Unfortunately, much of the world leadership, both corporate and governmental, does not recognize the past 150 years as a period in which the human race for the first time in history could hope that tomorrow might be better than today. Such hope is largely a result of the wealth-creating capabilities of the industrial revolution. Science and technology have become the primary architects of the human condition, change and history, but we are still writing history books as though worn philosophies are the prime movers in society. When people began to walk into the laboratories in greater and greater numbers, mankind began a rapid climb out of a world of hopelessness and discouragement. It was then that the idea that "tomorrow might be better than today" began to be a reality.

Most of world's technological capability is not being utilized effectively to alleviate the world's economic problems and suffering. I hear so many corporate heads of basic research or heads of R & D complain that they have achieved breakthroughs in product or process possibilities that might rejuvenate the industry or the company, but the lack of insight on the part of the top management or the chief executive officer regarding these breakthroughs and the lack of entrepreneurial interest or ability throughout the entire organization prevents further utilization. About ten years ago, I was talking with the director of research at one of the major steel companies in the United States. This particular vice president for research said, "In my laboratory we have achieved breakthroughs that could remake both the process and product profile of this corporation. My marketing manager's idea of a breakthrough is a new process for the factory which, if introduced, can help him undersell his competition by twenty or twenty-five percent. He does not really want a new product. The production manager's idea of a breakthrough is a new product that he can produce with existing equipment. He does not really give a damn about what it is as long as he doesn't have to change the plant." The executive continued, "You know, I do not object to these attitudes on the part of these people. But then we all walk into the president's office and the president looks at the three of us and says, 'When you guys can agree, come back in.' This unfortunate attitude characterizes our company."

Much has been written about the current relative position of American research productivity and technological strength. Some authors have contended that our research posture has never been better. Others say that the paucity of research investment over the last four, five, ten years spells future military and economic disaster for both our country and our corporations. I do not intend to engage here in a discussion of the quality or magnitude of our research. I am far more concerned with the environment in which the total innovation process must take place; the process of moving an idea from invention R & D, through the product reality, through the entrepreneurial stage in the market, and into an ongoing reality as a business.

England, for example, has over the years displayed the highest quality of research capability (and development) in the jet engines, antibiotics and polymeric materials industries. But the governmental, corporate and social structures of Britain certainly have not been conducive to optimizing these innovations for the real benefit of the country.

Since 1945 we have witnessed some rather dramatic changes in the attitudes of the American government, the corporations and the American public toward research and development. Government and industry appropriated huge amounts of money for basic research. Large segments of the government administration and corporate management then sat back and waited for research to display its magic power. These passive observers were frequently disappointed, particularly those in our corporations.

We then saw in the late 1950's another significant development. Research and development must, many managements claimed, be channeled by the state and by the evident wants and needs of the marketplace. The marketing executives gained unprecedented power over the selection of R & D projects, and genuine new product innovation was rarely the result. Product modification or improvement was the standard achievement. The words of Cyril Smith, who was Institute Professor at MIT, must be heeded: "History shows that technology originated far more often in curiosity and aesthetic urges than in perceived usefulness. Necessity is not the mother of invention -- only of improvement."

The economic recession of the early 1960's witnessed the placement in general management of individuals whose background and training were primarily in finance. Expenses had to be cut, and all too often the relatively far-out research was the first casualty. What made the situation ridiculous is that basic research is quite cheap considering the high pay-out it yields when the research is really supported and programmed by competent corporate executive leadership.

Why have all of these fads, if you will, imposed themselves on our corporations since 1955? Quite accidently in 1951, I had the pleasure of sitting next to Irving Langmuir, then the Dean of American Scientists. He said something which I have never forgotten: "The most formidable threat to research and innovation in this country is the growing number of executives and politicians making decisions affecting research policy and expenditure, whose training and experience do not permit them to understand what it is all about." Need we say more?

Carl Prutton, former Dean of Case Institute of Technology and later Chief Research Executive Officer of one of America's largest corporations, said, "To realize ultimate potential from research, comprehension and active participation by top corporate management are required. General and executive management has a greater responsibility for the overall end result, successful economic prosecution and marketplace success, than does a research manager of the organization. In a modern era of rapidly changing technology, the ability to program research and technology effectively is becoming an absolute requirement in the selection of corporate general management." The individuals who guided the growth of industries like DuPont, Texas Instruments, Hewlett-Packard, IBM, Polaroid, and 3M understood this principle very clearly. Such institutions have been growing at three times the rate of their low-technology counterparts, producing new employment almost ten times as rapidly, improving productivity at twice the rate and increasing prices only twenty percent as quickly as comparable low-technology firms.

I am always fascinated by the fact that when I come to a conference on the subjects of R & D, innovation, new product development, or entrepreneurship -- things that involve changing an organization's technology or product profile -- I find very few chief executive officers. The corporate presidents will allow and even encourage their associates from the R & D divisions to attend such meetings, but they rarely, if ever, show up themselves.

At this point we need to ask what the primary mission of our corporations is. I know that many would say it is the making of money for stockholders. Well, if this is the primary mission, if this is the reason for the corporation's existence, I would suggest that many corporations ought to be liquidated, sold at book value, and the money invested in tax-exempt bonds. Most corporations rarely earn more than a six percent ROI after taxes. Making a profit is a necessary tactic in the operation of our corporations; the more we make, legitimately, the better. But there is a more basic reason for the existence of the American corporations. The corporation was founded, and exists today, to take useful human knowledge (technology), move it into products or services, and move these into the marketplace. This is what motivates people to start corporations. Founders fully know that if they succeed in this objective they will make money, and they know that to stay alive they must make money. But corporations pursue a profit in order to be able to carry out this innovative process. They do this within whatever financial limits the corporation must accept, within whatever organizational and manpower limits the company may have, and within whatever legal limits they must recognize. I keep telling our vice presidents in charge of these limits, "Look, your job is to open up the limits; don't narrow them." And I would like to say the same thing to the government: "You must help me to open up the limits, as the Japanese government does." My primary preoccupation as chief executive officer is to enact the innovation-production-marketing procedure. If top management accepts this as the basic reason for the corporation's existence, the corporation is likely to survive. I think long-term survival is a greater challenge for our corporations than short-term profit. Only if top management accepts this survival responsibility will a given corporation continue to serve all of its *stake*holders -- the customers, stockholders, employees, and society in general. We say frequently that the stockholders really run and own a company, but I have often wondered what would happen if all of the stockholders in the General Electric Company, for example, met and decided to liquidate their company. Do you really believe that they could do it? I think that the next morning the unions, the government and others would make sure that General Electric continued to serve its function. We have made sure that Lockheed and Chrysler continue to serve their missions, even while they are not making a profit; other stakeholders must be served. The various stakeholders' voices are becoming at least as loud as those of the stockholders, and in many cases louder. During a recent talk with an officer of Dow, this was made clear. He said, "You know, we have far fewer rumblings from and troubles with our stockholders than we have with the public in general. This became clear at our gates one day, when a crowd demonstrated against the production of napalm. We never expected that degree of protest from the public."

If science and technology are the most powerful agents for change, and if advancing them is the primary function of a corporation, then we need 'leaders' of a new type, possessing different training and experience than those that have historically managed most of our corporations. I say most; IBM, 3M, DuPont, Hewlett-Packard, and Texas Instruments are exceptions. The great bulk of the American corporations, however, are not in that wonderful position of being saved by technological innovation in world market competition. Many of our corporations are overmanaged and underled; leadership implies, in addition to the effective management of an institution, the ability to conceptualize the future. Without this conceptualizing ability at the top of an organization, the process of innovation through the use of new knowledge will be seriously inhibited, if it occurs at all.

A fascinating article appeared recently in the *Harvard Business Review*, entitled "Managing Technology: A Box of Cigars for Brad." It clearly pointed out that the preoccupation of many top managements with current problems, legal matters, financial manipulation, and personnel activity now dominates a disproportionate amount of an executive's time. Executives spend a relatively small percentage of their days in the development of new product and market strategy, and in playing a significant role in seeing that the innovation process is effectively implemented. We need look no further to find reasons for the basic demise of many of our American corporations.

I would suggest that a number of changes be enacted, both in corporations and in society in general.

One: I think that government must encourage corporate leaders to accept innovation as a primary responsibility. Government should not by its endless regulations and paperwork force corporate management to spend most of its time as legal umpire, accounting scorekeeper, and operator of second-class welfare agencies. Executives must become deeply involved in this ball game called innovation. I'd like to tell a story about government regulation here, to introduce a bit of levity into the discussion and to emphasize a point. Back in 1885, a young man who had been bitten by a rabid dog was brought by his parents to Louis Pasteur. (I learned only recently, by the way, that only once in recorded medical history has someone recovered from rabies without treatment.) Joseph Meister had rabies, and his parents wanted Pasteur to innoculate the child. Pasteur had little clinical evidence that his vaccine was safe or effective, but the boy was going to die. Pasteur innoculated the child, and Joseph Meister recovered promptly. He died only eight years ago, at the ripe old age of 95 or thereabouts. Each day of his life, while passing Pasteur's tomb in Les Invalides, Joseph left a little flower. I often wonder where Meister would have been all those years if there had been an aggressive federal drug agency in France in 1885.

Two: Corporations and government must place in key management positions people who have a feel -- not the extended knowledge of R & D professionals, but a 'feel' -- for science, technology, the entrepreneurial process and innovation. The continued increase of the legalistic mentality, particularly in America, at the top of the corporate and government institutions will do little to enable us to promote the entire innovative process in industry. We have recently moved from promoting the finance man to promoting the legal man to the top job; it is the latest fad in reactive, crisis-oriented managerial selection. We put everybody at the top of our organizations except those whose primary responsibility and interest lies in enacting the innovative process.

Three: The American industrial scene and the American technological corporation need from our universities an entirely different School of Management (or School of Leadership) than has been characteristic of graduate business schools in the past. I do not think that the average business graduate in this country is prepared for the necessary retraining and upgrading of management and leadership for technology-based companies. For example, it is well known that if you need to retrain people for service in hotel management, you send them to Cornell or Denver. The reason is quite evident: they learn something about hotels at Cornell and Denver. There is no comparable school of management for executives of technology-based corporations.

I was surprised recently while visiting one of the more prestigious eastern business schools to hear its dean say, "For twenty-five years we have done nothing except train people to massage the existing institution. We have given people little indication or awareness of the need for injecting into that institution new technology, new products, a new entrepreneurial spirit. We are going to change this." I was astounded because although I often hear this expressed by engineering school deans, it is rare to hear it from the lips of a business school dean. The President of the United States, through Jordan Baruch, is enacting a program to emphasize the need in industry for people with an orientation toward innovation. Business school deans and engineering school deans will be placed in the same room sometime within the next six months. The results of this are hard to predict, but I strongly suggest that some university presidents should also be in that room, to help coordinate and synergise the willing and unwilling components of their institutions.

In closing, I want to emphasize that I do not believe that these problems are insoluble. Many of the difficulties concerning our need for increased innovation and increased industry-university cooperation would dissolve very rapidly if top corporate management would get into the innovation ball game. I also don't buy a myth I have heard expressed frequently, that the small corporation cannot undertake R & D or basic research. Conversely, in the same breath these same myth-makers will say that a large corporation is too inflexible to utilize the fruits of its research when it is completed. If we buy both of these concepts, we are really in the mud. There are large corporations with amazing flexibility and adaptability in enacting and utilizing innovation, and there are small corporations that do very effective basic research and get the results moved through their organizations.

There is no question, however, that if our entire innovation process is going to get into high gear, the top management of our institutions must assume the process as one of its major responsibilities.

BIOGRAPHICAL NOTE

Mr. Donald M. Alstadt is the president of Lord Corporation. He is a graduate of the University of Pittsburgh.

From 1946 to 1948, Mr. Alstadt served as a consultant to the Carborundum Company and has been a consultant to Transistor Products Company of Boston from 1952 to 1956.

During 1952-1953, Mr. Alstadt served as consultant to the Lincoln Project concerned with the Air Defense of the United States, and in 1956 to the Carnegie Foundation's efforts designed to reorganize the technical curricula of American universities. In 1963, Mr. Alstadt was a member of Governor Scranton's committee predicting the future of technological impact on Pennsylvania industry.

Mr. Alstadt is a Fellow of the American Institute of Chemists and a member of the American Physical Society, the American Chemical Society, the Faraday Society of England, the Electrochemical Society, the Chemists Club of New York, the Institute of Management Science, the American Management Association, and is a corporate member of the Conference Board.

Mr. Alstadt is currently a member of the Board of Advisors of the Case Western Reserve School of Management, the Board of Advisors of Case Institute of Technology, the Board of Visitors of the Graduate School of Business of the University of Pittsburgh. He is a trustee of the Rose-Hulman Institute of Technology, and a trustee and chairman of the Academic and Education Committee of the Polytechnic Institute of New York. He was formerly on the Board of Visitors of the School of Engineering of the University of Pittsburgh, the Board of Visitors of the School of Engineering of Tulane University, and the Board of Visitors of the Graduate School of Business of the University of Denver. Mr. Alstadt is a member of the President's Council of Fellows, Tulane University.

Mr. Alstadt is on the board of a number of companies, hospitals and banks. Mr. Alstadt is a member of the Advisory Board of Mellon Institute of Research (Carnegie-Mellon University). He is on the Advisory Council of the Kolff Foundation, an organization directed to artificial organ research and clinical application.

Mr. Alstadt was appointed in 1969 by President Nixon as Metropolitan Chairman of the National Alliance of Businessmen.

Recently, Mr. Alstadt has become active in the dynamics of the management of change in business and social institutions, and the technical innovation process in industry. His films "Human Attitudes and Managing Change," made in conjunction with National Educational Television, have been used by many industrial, educational, banking, and community groups.

Mr. Alstadt has been active particularly in liaison with the German and English basic chemical and rubber industries, and has been a frequent lecturer before American and European technical and management societies.

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Multinationalism and Cooperative Research

Mr. Charles F. Christ
Vice President, Xerox Corporation

As a multinational company, Xerox pursues cooperative research abroad as well as at home. Xerox benefits from Europe's longer experience in applied cooperative research in established relationships between Rank Xerox and European institutions with areas of expertise not found in the U.S., and from occasional cost savings resulting from government subsidies to foreign schools and institutes.

The problems with such foreign arrangements include: laws and government regulations concerning the export of technology, extended and circuitous lines of communication, and, occasionally, a certain rigidity in the approach of some government-sponsored institutes.

An interesting European phenomenon is the non-university applied research institute, often government-subsidized. A striking example of this is the TNO in the Netherlands, and there are others in the United Kingdom, France and West Germany. There are also a number of universities that offer their services directly to industry.

A Xerox project with Strathclyde University in Scotland illustrates some of the problems in international cooperative research. Because of proprietary Xerox technology involved, the information given to the university must be carefully controlled. The project is also complicated by the fact of its U.S. origin; Xerox in the U.S. retains responsibility for the work while Rank Xerox provides testing services and liaison. A project in West Germany, on the other hand, relates to a project for which a Rank Xerox unit is responsible, which simplifies communications and administration.

Xerox is working with the Dutch Organization for Applied Scientific Research on advanced metal forming, shaft-wear problems and optical development. Other Xerox cooperative research projects in Europe include a welding study at the National Engineering Laboratories in Scotland and general ongoing participation at West Germany's Institute for Synthetic Materials Applied Research.

Participation in cooperative research abroad gives us valuable access to independently originated work and specialized expertise. It dovetails with our policy of assigning development work among our multinational units. It supplements our own research efforts, offering a potentially high return on our development-dollar investments.

I would like to review what we at Xerox have done in the area of cooperative research on a multinational basis, particularly in what we call "manufacturing research," which is really technologically oriented research conducted with the objective of bringing to a product some benefit in cost, function or performance. I will talk about what we are doing in cooperative research, some of the institutions that we are working with, some of the projects we have going on, and some of the problems we have run into. Additionally, I'll discuss the boundaries of responsibility between engineering and manufacturing, what the design process is all about, and what has worked well for us within Xerox.

Cooperative research is no novelty at Xerox Corporation. We entered our era of xerography by acquiring the rights to that process from Battelle Memorial Institute, or the Battelle Development Corporation as it was then known, and by developing it along with them. To this day, Battelle continues to do a large amount of work for Xerox.

But cooperative research in manufacturing is a relatively new exercise for us; we have been at it only since 1976 or 1977. It has been extremely helpful in increasing the productivity of Xerox in terms of what we deliver to the marketplace. We measure our product against the products of our competitors, examining how much product performance per dollar of product cost we deliver to the marketplace as compared with the performance of our competitors. Over the past three or four years we have been able to increase this by about thirty percent, and much of the increase was brought about through cooperative manufacturing research projects.

We are very pleased with the results of these cooperative research projects, one of which is the Polymer Processing Program at MIT. There are a number of others underway in the United States. At the University of Delaware, we are involved in a study of advanced composite materials. The Stanford Research Institute is helping us to understand some problems in the area of automated manufacturing, and we are hoping to benefit from productivity studies currently underway at Rensselaer.

But Xerox is a multinational company in every respect of our operations, including research and development, and certainly in cooperative manufacturing research. Adopting a multinational approach to cooperative research has provided us with many benefits. Obviously, it supplements the resources of Rank Xerox, our European affiliate, which has research and development responsibilities in Europe. Our international cooperative research also takes advantage of the opportunities in relationships which have been established over a period of time with European universities and institutions. But our foreign research is by no means limited to the work initiated within Rank Xerox. Many of the projects conducted today in Europe were initiated in the United States operation and are managed from here.

This international approach allows us to take advantage of the expertise in a given field regardless of where it is located. Beyond this, there are several other advantages to working abroad. We have found that Europe's longer history of cooperative applied research has resulted in the people and institutions there being much more attuned to working to satisfy the needs of industry than is the case in many U.S. institutions.

There are also potential cost benefits in many instances, because a number of foreign institutions receive some form of government subsidy and support. Therefore, the fees charged to industrial clients may not have to cover the total cost, as would be required in a similar institution in this country.

But if there are special benefits in conducting research abroad, there are also special problems. One that is particularly bothersome to industrial companies is the problem of disclosure, which to a degree also exists in the U.S. It is natural for the university to want to share its research findings through publication, but where proprietary research is involved corporations must often insist on confidentiality. The disclosure problem is further complicated in international arrangements by legal restrictions on technology exchange and sometimes even by the way research agreements are written. Technology is considered an exportable or importable commodity subject to control under the laws of many nations, including our own, and we must work within the framework of these laws. The United States, for instance, regulates disclosure for both national security and foreign policy reasons. In many instances, a validated U.S. government license is required before any technical information can be disclosed abroad. Additionally, there are many special limitations on what can be disclosed to the Eastern block countries, limitations increasingly severe because of recent Middle East problems.

Another area that often causes difficulty is patent rights. For example, if a patent is applied for in the United States and a foreign patent application is filed less than six months after the U.S. filing, any resultant U.S. patent could be invalid. It is possible to work around the problem by getting an authorized U.S. patent of its license, but the situation makes the job much more difficult as far as coordinating, managing, and taking advantage of the work that can be done both here and abroad.

Problems may also be created by the laws of the foreign country in which the research is to take place. For example, the terms of international technology agreements are scrutinized very carefully by Japan's Ministry of International Trade and Industry. If the Ministry feels that the terms of an agreement are harmful to the Japanese organization or to Japan's national interest, it can withhold government approval. Such limitations can affect projects in which U.S.-created technology is assigned to a foreign unit of the company for technical development. At Xerox we make a very strong effort to identify a technology development role for our foreign operations. We do not feel that the U.S. is the source of all the best or the newest ideas in the world; we have, in fact, made a major effort to take advantage of what is happening in Europe.

Direct financial restrictions can also cause difficulties, depending on how you choose to share the monetary benefits of technical development. Brazil, for instance, limits the amount of royalties a Brazilian subsidiary may pay its foreign parent company.

These government regulations and the question of disclosure are not the only problems to be found in pursuing cooperative research abroad. The inherently extended and sometimes torturous lines of communication can create severe difficulties. Finally, the procedural rigidity in some foreign research institutions makes it difficult to tailor a project precisely to our needs, particularly when a foreign national government is involved in the program.

Once these hurdles are overcome, however, conducting cooperative research activities is much the same in Europe as in the United States. Company-university relationships are usually focused on specific projects which are under the direction of a senior faculty member working with his own assistants. An interesting variant to this is found in Japanese corporations, which make a practice of sending their young professionals to graduate school after they have been with the company for about two years. Therefore, when the company sponsors a university project, its own people are apt to work on the project as part of their graduate studies. This practice certainly helps to focus the work more precisely on the needs of the company.

A common European approach to third party research is the partially or wholly government-supported institute, which may be a standard organization or a research consortium. While in the past most of these organizations were essentially self-contained, there is today a growing tendency among them to collaborate with universities.

One particularly good example, and one with which we have had significant involvement, is the Dutch TNO, the Organization for Applied Scientific Research. TNO was created by the Dutch Parliament in 1930, and today is a sizeable organization dedicated to applied research in many areas. Industrial research occupies about one third of the organization. Its equipment is financed by the government, but its operating funds and the capital funds for its physical plant are expected to come from client fees. (The Dutch government, however, does on occasion make up for shortfalls in TNO's revenue.) TNO accepts proprietary development assignments in a broad range of areas from industrial clients, and eighteen percent of its private sector revenues in the past year has come from private sector clients. For a number of years, TNO has operated a center for physical research with the Netherlands Technical University. The center is involved in fundamental as well as applied research, and serves as a resource for other TNO activities. In addition, a number of other universities have recently begun working closely with them in applied research projects.

West Germany has its Institute for Plastics Processing in Aachen. In France, there is CETIM, the Industrial Manufacturing Technical Institute; in Britain, the Production Research Engineers Association; and the National Engineering Laboratories in Scotland.

Xerox is making extensive use of several of these institutes, and of certain foreign universities as well. One of our university projects offers a good example of both the problems to be overcome and the unique opportunities to be gained in an international cooperative research endeavor. We had in our own laboratories in the U.S. done enough preliminary work to show that we could achieve important improvements through a new approach to the production of toner (dry ink) used in one of our established copier products. However, our own development people were committed to work on totally new products and new materials. Rank Xerox had an established working relationship with Strathclyde University in Glasgow, Scotland, and Strathclyde has some special expertise that was particularly useful for toner work. So a project with Strathclyde to begin developing the procedure was established.

The organization of this project is interesting. My own manufacturing technology organization and the reprographics manufacturing group have budgetary and technical responsibility for project execution. Rank Xerox provides the daily management and serves as liaison between Strathclyde and my organization in the U.S. It is also responsible for testing the samples produced by the Strathclyde researchers as they develop the procedure. One other critical element is the assignment of responsibilities. The toner itself was originally developed by a reprographics technology group which is our product design arm in the United States. This group, therefore, has final design authority and responsibility for certifying the end results of the Strathclyde work. So, project management resides in reprographics manufacturing and works through Rank Xerox, which provides liaison and day-to-day support and testing capability. In turn, we in reprographics manufacturing coordinate the results with the reprographics technology group for final technical approval, and are responsible for implementing the procedure in the United States operations as well as in Europe.

Because we were dealing with a proprietary Xerox technology of critical importance, we found it necessary to take the strongest possible precautions. Our approach to control was two-fold. Rank Xerox obtained a nondisclosure agreement from both the university and its project researchers. In addition, we have not passed on any information relating to the xerographic development system. Rank Xerox translates all testing information into basic electrical, physical and chemical terms before transmitting it to the Strathclyde researchers.

Things are much easier when a foreign research laboratory is retained to develop a process that has no bearing on your own proprietary technology. For example, we are wholly funding a study at the University of Aachen in advanced manufacturing technology for a machine component. I cannot say more about it because it will be a proprietary technology developed by the University for Xerox and the patent rights will reside with us. In this kind of situation there are no constraints on communication between the American client and the contracting foreign laboratory.

We have a number of other projects in progress abroad. TNO's Metal Institute is working on a proprietary project in hydro-forming that was commissioned by Rank Xerox. And TNO's Tribotechnical Institute* is studying problems of wear for us. The TNO Technical University Center for Physical Research is working on a development in optics for us. Scotland's National Engineering Laboratory* is conducting a welding project commissioned by Xerox in the United States with Rank Xerox again providing technical liaison. (None of these projects, incidentally, is burdened by export or disclosure restrictions.) We also recently joined West Germany's Institute for Plastic Processing Research, and expect this new association to give us valuable know-how in areas ranging from outsert molding to electro-magnetic shielding with conductive plastics.

Clearly, foreign cooperative research in support of manufacturing is working well for Xerox. It supplements our internal staff resources, and makes available worldwide expertise in a given interest area. Foreign cooperative research ties in closely with our policy of assigning development work to Xerox organizations outside the United States. In short, it has helped us on a multinational basis to realize the greatest possible return on our research and development dollars. It is a practice which, for all of the difficulties we have had in its implementation, I can heartily recommend.

We must recognize the importance of organizing for technology and research, particularly for manufacturing research as distinct from basic research. We make, within Xerox, a concerted effort to understand what is going on in research and development at universities and technical institutes around the world. We do not wait for the universities to come to us with a proposal; we go out to find who is doing what where, and what they are good at. Understanding who is good at what and understanding the technology the corporation needs to bring a new product to market, or to reduce the cost or improve the capabilities of that product, is the role that my organization plays.

We have people physically located within the design engineering organization who facilitate technology transfer. They are members of the subsystem design teams working day to day and side by side with the engineers. As part of the engineering process, their role is that of a "technical broker." They are there to contribute, and to bring to the design process an understanding of what is unique and available in materials, material applications, materials processing techniques or design approaches that in a manufacturing sense will result in a lower-cost and better-performing product.

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*These projects have since been successfully completed.

At the same time, my organization has the responsibility of bringing that product all the way from synthesis, when we are first trying to figure out what will satisfy a market need, to production at line balance. Only then do I hand over the responsibility to the manufacturing manager, who runs the plant day to day. Up until that time, the product is my responsibility and I must solve any problem associated with it.

In having an organization that reaches from the very early stages of product definition to actual production, we have eliminated some of the functional boundaries that used to impede the transfer of technology. We have also overcome many of the problems in getting the manufacturing operation to accept change, and in getting the engineering operation to accept new ideas (an equally severe problem). In the past, given the necessary lead times and launch dates, it was often the case that by the time the production engineers could see what the product was going to be, it was too late for them to influence its design. On such and such day, in such and such year, we will launch a product; it will be there. Increasing the transfer of technology and the flow of communication is the only way we can overcome reluctance to adopt new technology on the part of the engineering organization. They know what the tried and true is, and what has worked before, and there is a great tendency on their part to want to stick with the familiar.

But to be able to bring the product cost down and shorten the development cycle, we have got to bridge that gap, overcome that barrier, and work as a team. We have been able to do that in the last two years, and the results are starting to show up in Xerox products today.

Questions

Edward E. David: What percentage of your R & D budget do you actually spend on some of these contracts?

Charles F. Christ: Keep in mind that I differentiated between research done by the Webster Research Center at Xerox, for instance, and that done by the engineering group. What I am talking about is what we call

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manufacturing research. This is really a technology-oriented activity and is not oriented towards basic fundamental knowledge. That budget is in the millions of dollars and we try to split it fifty-fifty between the U.S. and Europe.

Fred Haynes: To what extent do tax incentives drive you to do some of this research overseas in a foreign affiliate, where clearly, in a country with higher taxes, your international tax base will be reduced by these research efforts?

Mr. Christ: It is a consideration, but not a driving one. I mentioned it only because it is a unique aspect of doing business in Europe, where organizations such as TNO and others do receive, in some sense, a subsidy from the government. We drive primarily on a technology that can give us the best product, wherever it is. My prime goal is to reduce the cost. And we had a great tendency at Xerox, as in many companies, to want to do everything here ourselves. We have tried very hard to break out of that and to take advantage of whatever is available, wherever it is located.

BIOGRAPHICAL NOTE

Mr. Charles E. Christ is Vice President of Manufacturing Technology and Programs for Xerox Corporation's North American Manufacturing Division since 1978. He has worldwide responsibility within the Reprographics Manufacturing Group (RMG) for manufacturing research and development, technology transfer, and manufacturing program management.

In addition, he has responsibility for advanced manufacturing engineering, advanced quality engineering, industrial engineering, and manufacturing quality assurance.

Mr. Christ joined Xerox in October 1966 and has held a number of key management positions including manager of the company's materials manufacturing plant from 1974 to 1975, manager of the company's consumables manufacturing plant from 1975 to 1976, and manager of manufacturing technology from 1976 to 1978.

Mr. Christ holds a bachelor's degree in Industrial Engineering from General Motors Institute and a master's degree in Business Administration from Harvard University's Graduate School of Business.

The author of 15 technical articles, Mr. Christ is a member of the Industrial Advisory Board, Laboratory for Manufacturing and Productivity, at MIT.

PANEL III: Policy Recommendations

Participants:

Dr. Daniel C. Drucker, Chairman
Mr. Walter L. Abel
Dr. Arden L. Bement, Jr.
Mr. Howard J. Dugoff
Dr. Kent F. Hansen
Mr. William Wetmore

Mr. Walter L. Abel
Vice President for Research and Development,
Emhart Corporation

During this conference we have looked at the broad innovation spectrum, from basic research on one side to the nuts and bolts of manufacturing and engineering applications on the other. We need, in many areas, just good engineering applications of existing technologies.

To understand my conclusions you must understand the base from which I reason. I started with a highly centralized corporation where all decisions were made at corporate headquarters. We then went through a period during which authority was highly decentralized. Many times when the pendulum swings it goes too far and causes a new set of problems. Usually with a major change of activity in an organization, there is also a change in the organization's corporate management. We now find ourselves with many financial and legal people sitting at the decision-making positions. Now, once you turn a good financial person around so that he or she understands and appreciates technology, you have a good double-edged sword. If you do not turn these people around, you have problems.

I look at part of my job as internal marketing; I must talk to the correct people. It is easy to talk with the people here at this symposium; we are all thinking in a similar technical atmosphere. But I have to talk to nontechnical people and convince them how to get a completely proven new idea instituted. I must show them how to look at the future. People come to me and say, "Wally, why can't we get more of the computer-controlled pieces of equipment like the one that we can't keep up with the orders for?" I look them in the eye and say, "That took seven years to develop. That is a minimum. You will not put up three years of financing." In fact, it is hard sometimes to get them to put money up for only two years. I have to demonstrate to them that the biggest risk is not taking any risk. I find it very disturbing when I go to the divisions, and see division managers cutting out programs which are very basic for the future. They are not fighting for these programs. When I ask, "Why did you accept this?" they answer, "There was a budget cut." When I say, "Yes, but did you go back to management and describe the effects of the cut?" the answer is no.

A few years ago, back at the new corporate headquarters, I became very excited about the micro-revolution. Micros would turn the world upside down, if there were enough engineers trained to design the smart products, the smart machinery and the smart processes. I requested half a day of corporate management's time, and I brought in a dynamic micro expert, who told us what was coming; the smart products, machinery and processes. It was very successful, and for the next two weeks I had all types of people marching into my office saying, "Hey, Wally, can we use it here? What about this? What about that?" Suddenly it dawned on me that ninety-five percent of all the inquiries concerned manufacturing -- not new products, smart products or new machinery, but manufacturing. I grew up in research and development, where we came up with new principles, processes, machinery and products. Although I was aware of manufacturing, I was not really aware of what needs to be done there. So we called together representatives from different divisions. Sure enough, there was great need. People wanted to talk to each other, and all kinds of problems began to unfold. Then I said: "Let's get it on the right base." An outside manufacturing expert was called in to give us a full day on the state of the art of automatic manufacturing. Ten useful recommendations came out of that.

Along the way I picked up a young dynamic engineer trained in micro-electronics, and convinced him that his job for the future was with me. I thought, "Boy, we'll show them how to do distributed processing. We'll take the manufacturing and we'll divide it up. Then we'll put a micro here and a micro there and we'll bring them together with a host computer. We'll save money for the corporation!" I thought I'd develop the smart products later, because there was first so much to be done in manufacturing. What did we find? We had no engineering base to build on! In many places we did not have a good electrical or mechanical engineering base. We found technicians called 'manufacturing engineers' who had no engineering base. We did not have enough polymer engineers, industrial engineers, or project engineers. We concluded we had better search and search, and train, train, train.

I would like to shift gears a little, and talk about my experience with industrial-university co-op programs. Dick Berry and I helped Nam Suh to start the Polymer Processing Program, so I had a soft spot in my heart to make sure it was successful. For me it was necessary to find a division that would support the program after I provided the seed money. Financially, it came at the worst possible time. People who were supposed to be at the Polymer Program were often not there -- they were back home taking care of crises, and putting out fires. Decentralization and financial control lead to short-range thinking, and that leads to fire-fighting.

We did get back into the program because we started injection molding complete polyester fiberglass automobile front ends in one piece, using 2,500-ton presses. We also were involved in the reaction injection molding of urethanes. We can make a complete flexible front end for a car like the Chrysler Mirada in under two minutes. These projects are not for junior engineers! The director of that program looked at the Polymer Program and said, "Yes, I'd like the corporation to get back into it." So I had a division to support the Polymer Program again and we were back with Nam. Well, then this division had problems. They, like the previous division, were back home fighting fires instead of following the program and proceeding with fundamental projects.

So the nature of the beast is short-range, day to day work. What do you do? We did pull together several internal groups, like the computer control group and the CAD/CAM Society. We are also working on the notion that big companies need little companies and little companies need big companies. And the entrepreneurs, for example; where do you find them and how do you work with them? When your organization is fragmented and decentralized, these are the kinds of steps you consider.

Although all of these activities have been valuable, from an overall corporate viewpoint you still need fresh new ideas, tools and technology. We need new, technically trained people. We need a way to revitalize and motivate existing technical people. We are aware of new generic technologies that would be useful to many divisions throughout Emhart, but I find no one division or group that will provide the funds to do the work. We need a dynamic push in all manufacturing areas to strengthen our engineering base, not only for better price, quality and delivery, but

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even more importantly for CAD CAM. As far as I am concerned, CAD CAM is a must for the future survival of any manufacturing group. What are we going to do about it? Why not make a better coupling between industry and the university? The universities are the base source for technically trained people, the source for the fundamental understanding of the existing technologies and the fountainhead of new technologies. However, our experience to date has left much to be desired.

Now, knowing all of the benefits we can receive from this coupling with the universities, we asked ourselves what we could do differently to make such interaction more effective than it has been in the past. One, Emhart should have a *physical presence*, a small office and lab, located at the university. Those people who are serving research needs have one set of conditions, and those in manufacturing have an entirely different set of needs. What is good for one is not necessarily good for the other. So, as a policy, leave the door open for a give-and-take atmosphere. I want a full-time lab director who will report to the corporate V.P. for R & D, and who will live in the vicinity of the university and provide a bridge between it and Emhart. Two, division engineers with projects should be assigned for a limited time to the center. In this way, the center will be their top priority while they are away from home.

Now, what are our conclusions about this type of coupling? With only a few people related directly to the university, we receive a critical mass effect. This is needed for new ideas and for applications of new technologies. Of great importance, we will have day to day and face to face communication with faculty and students. We can get things settled rapidly on the spot. The project engineer, while at the center, can have some of his rust removed and at the same time receive new ideas to apply to his projects.

The center will provide a window for us to look at the university and the students, and vice versa. We expect that, being at the university, we will be called upon to give talks and lectures concerning what industry is all about and how business is run. Importantly, the center could be a holding tank for our new employees. We could use it as a central point, and fan out employees to other divisions before we firmly assign that new employee within Emhart. We can pull in the international information activity that is going on in many of the universities. We expect the center to tie into other centers and not duplicate work.

We believe that this form of cooperative action could go a long way towards helping Emhart with its problems. Of more importance, many centers will help the U.S. to improve its innovation, and I am convinced they will improve U.S. productivity.

BIOGRAPHICAL NOTE

Mr. Walter L. Abel graduated from Worcester Polytechnic Institute in 1939 with a B.S. degree in mechanical engineering.

He joined the Research Division of USM Corporation in 1939 and has been associated with them in various positions since that time. Following an extensive training course which covered all phases of manufacturing, development and research, he was assigned as project engineer on process machinery for the shoe industry.

During World War II, Mr. Abel worked on mechanical computers for anti-aircraft, followed by project engineer work on rocket-propelled aerial torpedoes. He was next assigned the task of organizing a new research department and later became head of that department. Shortly thereafter, he was named assistant director of research for the company. In 1961, he became director of research. Mr. Abel headed up the Central Research Division when it was formed in August of 1966. He was named assistant vice president of research in March 1967 and became vice president of research in March 1969.

In 1976, USM became a subsidiary of Emhart Corporation, and Mr. Abel retained his title. In 1979, he was appointed Vice President for Research and Development of Emhart Corporation.

Mr. Abel was active in the management area on the Program Committee for the Boston Section of the American Society of Mechanical Engineers.

He attended the Program for Senior Executives at MIT, Spring Session, 1958 and the MIT Executive Refresher Course, in the fall of 1964. In 1973, he became a member of the MIT Corporation Visiting Committee, Department of Mechanical Engineering. He is also a member of the Industrial Advisory Board of the MIT Laboratory for Manufacturing and Productivity, and a member of the Industrial Advisory Committee of the University of Hartford. In November 1979, Mr. Abel was elected to the Board of Directors of Computer Aided Manufacturing International (CAM-I); in the same month, he became a member of the Board of Advisors, Department of Management, Worcester Polytechnic Institute.

Mr. Abel is past chairman of the Boston Research Directors and is a member of the Industrial Research Club of New York. In addition, he is currently USM's representative in the Industrial Research Institute (representing about eighty percent of the industrial research in the U.S.A.). In May 1968, Mr. Abel was elected to the Board of Directors of the IRI, and he assumed the presidency in May 1972.

Mr. Abel is the 1970 recipient of the Robert H. Goddard Award, Worcester Polytechnic Institute.

Dr. Arden L. Bement, Jr.
Director, Materials Sciences Office,
Advanced Research Projects Agency

I am going to address the question of policy from the perspective of a government mission agency.

The science and technology program within the Department of Defense is a multiple spectrum program consisting of a research program funded at $600 million, an exploratory development program at $1,800 million, an advanced technology development program aimed at specific demonstration projects and funded at about $600 million, a manufacturing technology program at $156 million, and the defense advanced research projects agency at over $500 million. If you add the independent research and development programs within industry, there is an additional $1.6 billion. We are talking about a very large infrastructure. Coupling is done at all levels in the science and technology program, although the nature of the coupling and the cooperation varies. For example, coupling between the DOD laboratories and universities would be much more prevalent in the research program than it would be in the exploratory development program, where industry-university coupling would be stronger.

The cooperation comes about in two main ways. Within the Department of Defense, we have a built-in user community at all levels. Many project managers are trained to optimize resource allocation and to achieve leverage and amplification wherever possible. In order to take a new concept from proven scientific feasibility to technical feasibility quickly, it only makes sense to couple basic scientific insight with technical insight. If I were to describe all of the ways in which coupling is done in these programs, it would take much more time than is warranted. The DOD laboratories play a very essential role as a catalyst. They do most of the contracting within the Department of Defense for the out-of-house research programs.

By and large, we try not to do coupling for the sake of coupling. We try not to stereotype coupling, and recognize that there is no preferred model. It is customized, and depends on the nature of the research, the partners that come together to do the research and a lot of other factors. Mostly what we can do is create a climate for cooperation. The first step is to perceive the nature of the problem. From my point of view, in defense research innovation is not the major problem. We do try to keep track of our technological lead time in regard to the risk of technological surprise in several critical defense sciences vis-a-vis the Soviet block. Since our resources are about half of the Soviets', there is always a high risk of decreasing our lead in a specific program area, and not perceiving it because their programs are cloaked in secrecy. Nevertheless, in many of the major defense sciences we do enjoy about a three- to five-year lead. The problem comes when you begin examining the technology embedded in new defense hardware; there, the lead time is not so great. In fact, in some areas we are clearly behind. So our real problem is the implementation of existing technology. We have an inflation of productivity which is outstripping our economic inflation. On the average, there is a three-year production lead time across the Department of Defense and it is increasing at the rate of one month per month due to problems in critical materials, critical manpower, critical equipment and in some areas, critical commodities.

That is where we have to apply our leverage, and the question is: what policies are needed to create a conducive climate and a better outlook for cooperation? First and foremost in the Defense Department, where we are dealing with three services, multiple commands and a laboratory structure of over seventy laboratories, you have to approach the problem from the standpoint of winning agreements and not from the standpoint of winning battles. In my estimate Japan is successful in the marketplace and is gaining a march on us because it operates from this viewpoint.

Secondly, a rational approach to return on investment is required. Since we are in the Center for Advanced Engineering Studies, I feel obliged to quote Myron Tribus, who argues that the approach taught in many business schools is based on three human weaknesses: greed, impatience and fear. Greed in that one wants a high pay-off, impatience because one wants it as soon as possible and fear in that he wants it at minimum risk. It is necessary to inject foresight, patience and the courage of your convictions into your approach.

Next, it is possible to approach the management of exploratory development, and even some research programs (when they are need-oriented), from an investment management point of view. In other words, provide focus and establish priorities. At the OSD level, we do this through our premium technologies program; the Very High Speed Integrated Circuit Program is one such program. By fencing resources and giving a high-executive level of priority to the program, long-term stability and continuity is injected into the program, subject of course to Congressional review. This is very conducive to cooperative efforts. Of the eleven proposals that have been submitted to date on the VHSIC program, at least nine of them involve consortia. Almost all of them involve university efforts in one form or another.

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It is also necessary to plan for success, and that means that we should not nickel and dime the program. In our 6.1 program, our research program, we are trying to find larger-scale efforts, more critical mass efforts and multi-investigator programs at universities in order to foster interactions on campus. The Office of Naval Research is also experimenting with operating in a more DARPA-like mode in some of its programs, by tying research together with exploratory development efforts. This has been very successful in the Advanced Research Projects Agency over the years.

There is also a need for reduced polarization. In the past, we have partitioned our program to solve near-term problems and address long-term opportunities. This means that industry is assigned the task of solving the near-term problems and the research program deals with the long-term opportunities. If you invert that investment strategy, it does a very curious thing. It creates a lot of overlap, and forces us to exploit our near-term opportunities and to try to solve long-term requirements.

The Defense Department, through its Science and Technology program, practices resource pooling wherever possible by carrying on cooperative programs with other agencies. For example, we have arrived at a memorandum of understanding with the National Science Foundation. We see benefits of cooperation between the DARPA, the VSLI Program and the VHSIC Program with their microstructures program, and are investing in facilities in research programs at major universities throughout the country to provide advanced capabilities on university campuses and to tie those in with industrial capabilities. We also have a program between the Department of Defense and the National Bureau of Standards in integrated circuit reliability and measurements and in rapid solidification processing.

We have provided program support for technology centers. Two are here at MIT -- the Laboratory for Manufacturing and Productivity and the Materials Processing Center, which has been recently inaugurated. We have to be somewhat careful not to preempt the resources that are already available, which would be the case were we to enter into cooperative support at too high a level in some of the generic technology centers.

Next, we try to balance our business policies with our technical policy. The main interface is between my office and the Office of Acquisition Policy, which comes in two areas: the Manufacturing Technology Program and the Independent Research and Development Program. Manufacturing technology is presently funded out of procurement funding, so it is necessary to be able to demonstrate a deliverable product. We are trying to incorporate more manufacturing and process science activities within our research program to help close the interface with the demonstration of projects coming out of the procurement funding. In independent research and development we have to be very careful that we do not encroach on its independence, the main element and benefit of that program. Unfortunately, these programs can be characterized with a small "r" and a large "D", and except for some marginal activities, very little of it is invested in universities. There has been some consideration given to providing incentives for cooperative research ventures with universities through a reimbursement schedule.

Finally, there is a need to improve science technology and information services to the private sector. Many of the major new technologies that have emerged since the second World War through investment in defense science and technology are input to the private sector. We have reorganized the Defense Documentation Center and now call it the Defense Technical Information Center, to reflect its role in tying together all of the information centers within the Department of Defense. We expect it to emphasize the establishment of data banks and management information centers and other such services. These capabilities must be linked with the National Technical Information Center and the Library of Congress. It is necessary to provide much more 'internetting' of national information centers for the universities, the academic community and industry at large. We will be working very hard during the next year to establish an information base for such programs as manufacturing technology, human behavior and VHSIC.

BIOGRAPHICAL NOTE

Dr. Arden L. Bement, Jr., Deputy Under Secretary of Defense for Research and Engineering (Research and Advanced Technology), is responsible for overall management of the science and technology programs of the Department of Defense and for related activities such as manufacturing technology and monitorship of the Defense in-house laboratories and Federal Contract Research Centers. These programs have an aggregate annual budget of more than three billion dollars.

Dr. Bement earned an engineering degree in metallurgy at the Colorado School of Mines in 1954 and advanced degrees in metallurgical engineering (M.S., University of Idaho, 1959; Ph.D., University of Michigan, 1963). He began his professional career as a research metallurgist and reactor project engineer with General Electric at the Hanford Atomic Products Operation, Richland, Washington. From 1954 to 1965, Dr. Bement conducted fundamental and applied research studies in nuclear fuels, reactor structural materials, radiation effects, and mechanical behavior of advanced materials. During a leave of absence, Dr. Bement served on active duty with the U.S. Army Corps of Engineers (1955-56).

With the change of contractor for the Hanford Laboratories from General Electric to Battelle Memorial Institute by the USAEC in 1965, Dr. Bement advanced through a series of management positions to manager of the Fuels and Materials Department, 1968-70, where he was responsible for programs in nuclear structural materials, defense technology, biomaterials, manufacturing technology, and the design, fabrication, and irradiation testing of advanced nuclear fuels.

In 1970, Dr. Bement joined the faculty at MIT as professor of nuclear materials and developed academic and research programs in support of advanced energy conversion technologies, such as fast breeder and controlled thermonuclear reactors and magnetohydrodynamic generators. From 1974 to 1976, as a member of the US-USSR Bilateral Exchange Program in Magnetohydrodynamics, Dr. Bement organized and was principal investigator of the MIT Fusion Technology Program. He has consulted with several industrial firms, the Advisory Committee on Reactor Safeguard, and the Government of Taiwan and Mexico in energy and materials technologies.

From June 1976 through November 1979, Dr. Bement was director of materials sciences, Defense Advanced Research Projects Agency, and was responsible for approximately $30 million of sponsored research in structural, optical and electronic materials for advanced defense systems.

Dr. Bement has edited three books and has authored over seventy publications in various areas of materials science and energy technology. He is a fellow of the American Nuclear Society, the American Society for Metals, and the American Institute of Chemists, and has received several professional awards and honors. He is listed in *Who's Who in America* and *American Men and Women in Science*. He has been active in public service as a councilman, city of Richland, Washington (1968-70) and as chairman of boards and councils in the fields of health, equal opportunity and the arts.

Mr. Howard J. Dugoff
Administrator, Research and Special Programs Administration, Department of Transportation

Like the two panelists who spoke before me, and like just about everybody here, I approach the subject under consideration from a specialized perspective. I have been involved in the planning and development of the Cooperative Auto Research Program, and my attitudes and knowledge on the subject of cooperative research derive primarily from that exposure. I will talk here very briefly about some of the background and rationale of the Cooperative Auto Research Program and present some general recommendations that my panel colleagues and I have synthesized from the cooperative experience.

The fundamental premises of the Auto Program are, first, that a better basic understanding in the various disciplines of engineering science will lead to advances in automotive technology; second, that current investments in these areas are inadequate; and finally, that advances in automotive technology are in the national interest. It follows from these premises that the Federal Government ought to do something to stimulate additional research in these disciplines.

The first question that might be asked is, "Why establish a cooperative program to accomplish this objective? Why not, for example, just beef up NSF support in these disciplines?" Well, I think that there are two important reasons why a cooperative program involving the industry as a partner with the Federal Government is appropriate and desirable. First, it is an equity consideration to the extent that advances in these disciplines will advance automotive technology. The research will contribute to the purposes of the automobile industry. Consequently, members of that industry ought to contribute to the support of the program. Second, very active participation as a member in a cooperative program will provide important benefits of an educational and consciousness-raising character to industry members.

The second reason, the educational benefit, is also the rationale for the participation of the mission agency associated with the automotive sector; namely, the Department of Transportation. By participating in the planning and monitoring of this research activity, the personnel in the Department of Transportation will enjoy the same educational benefits and advantages that the members of industry do.

My colleagues on the panel and I have discussed this matter at length and from it we have synthesized the following general policy statement: basic research in the engineering disciplines underlying the technology of an industrial sector that is important to the national economy is a suitable topic for a cooperative research program involving members of that sector, the associated government mission and research agencies and, as the principal performers, the nation's academic institutions.

Now, because the Auto Program is a program of basic research, many of the issues related to the inherent conflicts in perspective between industrial and academic institutions could be relatively easily resolved in a fashion that is particularly agreeable to the academics. The time scale for any basic research is, by definition, long-term. Proprietary considerations in basic research are not generally substantial, and consequently the wide and open dissemination of results is not a problem. I should think that these considerations would make the nature of the Cooperative Auto Program particularly attractive to academic institutions. However, the relative absence of proprietary content implies relatively little direct opportunity for the achievement by industrial participants of immediate commercial advantage. As I noted earlier, the benefits that they are expected to derive from the program are substantially educational. Generally, I do not think that this benefit is construed by industrial organizations as sufficiently valuable to warrant the underwriting of the total cost of such a program.

That is why it was necessary for the Federal Government to participate financially. This gives rise to the second general principle the panel wishes to advance.

We start from a general principle that was stated yesterday by Dr. Perkins: that the government's role in cooperative programs should be kept to a minimum. In particular, in programs involving activity that ultimately can create proprietary benefits, the government's role should be restricted to the start, and it should pull out as soon as possible. However, in cases where the interest of industry is not directly served to a sufficient extent by the cooperative program, but a distinct national interest is served, it appears appropriate to us that public funds be considered as a legitimate contribution over the indefinite term. We also believe that indefinite federal support may be appropriate in ventures with highly fragmented industries, which include large numbers of relatively small industrial participants and do not provide enough incentive for such small players to fully underwrite the cost of a generic technology center, for example. If it is in the national interest to foster the technology in this industry, we argue the legitimacy of indefinite federal support.

BIOGRAPHICAL NOTE

Mr. Howard J. Dugoff has been administrator of the Department of Transportation's Research and Special Programs Administration since 1979. From 1975 to 1979, he served as chief of the Handling and Stability Division and then as associate and deputy administrators for the Transportation Department's National Highway Traffic Safety Administration.

A graduate of the Stevens Institute of Technology with a B.S. in mechanical engineering and an M.S. in physics, Mr. Dugoff was awarded the Administrator's Award by the National Highway Traffic Safety Administration in 1976, and the Research and Development Achievement Award by the Department of the Army in 1973.

Dr. Kent F. Hansen
Associate Dean of Engineering, MIT

The statement of purpose in the brochure for this conference asserts that "there has been concern that our national resources are not being effectively utilized in advancing technological innovation and industrial productivity." This statement reflects an implicit set of values and a set of social objectives which have, in fact, not been addressed by this conference. My personal policy recommendation deals with an examination of the relation between these objectives and the mechanisms that have been suggested to achieve them.

Listening to the speakers yesterday and today, I detected in their remarks a number of unspoken assumptions about the means of reaching these innovative and productivity goals. For example, some have suggested that more innovation will follow from the establishment of cooperative programs; that innovation itself will be good for the United States economy, for employment, for balance of trade, etcetera. It has been stated that U.S. industry will be stimulated to innovate if the Federal Government adopts certain policies, such as tax incentives, basic research support, generic research centers or depreciation allowances. Yet, with the exception of Dave Noble, who spoke yesterday but was not on the program [see discussion, Panel II, (ed.)], I have not heard anyone make allusion to the set of social values which, in turn, imply a set of social objectives out of which are derived a set of social programs. I think that all of us have an implicit, if not an explicit, set of these values and objectives. Furthermore, we have our own implicit models of how the system works. With these we then formulate the policies that are necessary to produce the objectives that we seek.

Collectively and individually, we all sometimes have experiences that make us think that the real system and our model are not closely related. For instance, in the 1950's and 60's there were massive urban renewal programs in our cities. The set of objectives, the model and the policies that were used to produce these programs are not now viewed as appropriate by urban study analysts for this decade. Very few of those programs are considered successful. Another example is in urban transit. I have lived in the Boston area for thirty years. In that interim I have found that the time required to go from point A to point B has stayed constant. Thanks to urban transit programs, the loci of traffic jams have shifted all over the city; yet these programs have not helped me get from A to B any more quickly.

I am not arguing that these are trivial problems which could be solved with the right policies. They are very complicated problems, and sometimes we leap to solutions before we understand the problems well enough. These experiments, if not failures, are certainly not successes. They suggest that we would do well to pay more attention to and be more explicit about the links between our values, our objectives and our programs. For instance, with regard to innovation and industrial development and the like, there are some questions that we might address parallel to carrying out the programs that have been suggested.

For instance, how much is known about the relationship between the dollar volume of research support and the generation of ideas? Are they proportional to each other? Are they inversely proportional? Is the generation of ideas independent of the amount of money spent on research? The answer to that question has some bearing on what policies we follow.

What is the relation between the growth of scientific knowledge and the growth of technology and invention? Do we have enough science base sitting there throbbing, waiting to be exploited by technologists? Do we have an inadequate amount of science? Is our technology held back by a lack of science and not by a lack of engineers? Again, the answer to that question is crucial to the policies that we propose.

What is the relationship between economic growth and innovation? I do not know the answer to that, but I think it is important. Does technical or economic progress develop because of a few giants, or does it move because of many small advances?

What is the time constant for the exploitation of science into technology? Historians have suggested that much of the industrial revolution in the nineteenth century was a result of seventeenth-century developments in mathematics. That implies a two-hundred-year time constant, which suggests that this conference is dealing with the welfare of twenty-second century citizens. On the other hand, perhaps the time constant itself changes with time, as a result of greater knowledge and information. Is this true? Who among us has the foresight to know now what science is needed to produce the technologies which would be desirable for our social objectives? Who among us has the foresight to see the social consequences of the new technologies we advocate? The questions of this kind are almost endless, but these few serve my purpose.

I suggest that, in conjunction with the cooperative programs that have been mentioned and will undoubtedly be carried out, we also carry out a parallel study aimed at clarifying our objectives. We should conduct a study that will provide a more explicit mode of the government-industry-university system. Such a study will provide vehicles for testing policy alternatives to gain some insight into how the system truly behaves, and will also serve to point out areas of specific ignorance which have high leverage. Thus, my policy recommendation is that we try to develop a means for the nondestructive testing of the policies that we recommend.

BIOGRAPHICAL NOTE

Dr. Kent F. Hansen received his S.B. in physics (1953) and his Sc.D. in engineering (1959) from the Massachusetts Institute of Technology and has been associated with MIT since 1959 in various capabilities, from research associate to professor to his present position as associate dean of the School of Engineering. Professionally interested in a wide range of subjects, from nuclear reactor theory and mathematics to engineering education, he is a member of the Society for Industrial and Applied Mathematics, the Association for Computing Machinery, the American Society for Engineering Education, and the American Nuclear Society. Dr. Hansen has also served as consultant to a variety of organizations including the U.S. Veterans Administration, Electricite de France and Los Alamos Scientific Laboratory.

Mr. William H. Wetmore
Director, Intergovernmental Science and Public Technology Division, National Science Foundation

There are four recommendations that I will discuss.

The first may be an issue to consider rather than a recommendation, because I am not sure we have the necessary information from which to make a recommendation. This issue deals with the fact that most supported research is in one of two classes: either proprietary or nonproprietary. The proprietary information is usually kept very close to home, and many times it is the nonproprietary information that ends up in the cooperative research centers. This makes us think that possibly the most important research is that which is not yet exposed. However, for all of the right reasons, proprietary work is not supported in the cooperative arrangements, which raises the question of the potential use of public funds for proprietary research. This further raises all kinds of issues concerning protections and responsibility, and I do not make a recommendation. I leave the question open for debate. If some stimulation through partnership can be achieved, what might be the opportunities for public support?

Second, we have in this country a rather significant base of professional engineers who provide extensive technical services to small and fragmented businesses. I think that we, in any federal program, want to take great care to insure that any technical assistance coming from the Federal Government does not encroach on the economic base and the growth of these professional engineers. The government should do all that it can to insure their economic development and the increase of their economic strength. I would propose that we consider recommendations which protect the private sector in its delivery of technical service, to insure that federal centers only act in areas which preserve the ability of growth in the professional engineering community.

Third, we have heard frequently that the agricultural model offers an analog that might be very helpful in determining policies and practices in the industrial sector. For the past two years the Foundation has supported some activities involving work with industries in all classes, such as at the University of Arkansas, using much of the analog from the agricultural extension program. At the same time we realize that there are important and unique differences between agriculture and industry today. Much more needs to be learned in this area. As soon as there is data that might shed more light upon the appropriateness of the agricultural model, we will do all we can to make it available.

Before I go to the fourth question or recommendation, I need to say a word or two about myself. I am from an engineering background with general, pragmatic experience. The issue I will address is somewhat intangible but not insignificant, and deals with some of the social values that might be attributed to innovation. I believe that attitudes affect and dictate actions; any program or action that we take reflects our own commitments and attitudes. In addition, the policy recommendations that we choose to make reflect our objectives. One objective that I support strongly is a change in the attitudes towards the United States' industry. We must realize that this industry is important to our standard of living, and to the tax base upon which our local, state and federal governments operate. Without this strong base we run into the persistent problems of inflation and unemployment. Recognition of the importance of U.S. industry is somehow getting blurred, and I think that it is important to reaffirm it. That ties in very closely with the stimulation of some action.

Today, I see a lot of polarization and adversary relationships: government versus industry, sometimes industry versus universities. There is a degree of tension that needs to be recognized, but the situation is not so serious that steps cannot be taken to improve it. Although there have been some failures, I think that U.S. industry has done a good job. The same is true of universities and of the Federal Government. But there is a great need to recognize opportunities and to find the basis for fuller cooperation. It seems clear to me that this would be in the national interest.

I am encouraged but cautious. It has taken us a while to get into our current situation, and I think we all realize that the solution to our problems will take a great amount of patience. There is a fairly long road ahead and the time constant may be longer than many would like.

My policy recommendation is that we continue to fund these cooperative centers and that we recognize that opportunities are there not only for research *per se*, but for the institutions involved.

It seems to me that a better understanding and the desire to cooperate is more extensive at the present time than it has been previously. So I will close on that note, and emphasize that attitude and desire and commitment are the strongest foundations for making these programs more effective.

BIOGRAPHICAL NOTE

Mr. William H. Wetmore has been with the Intergovernmental Science and Public Technology Division of the National Science Foundation since 1975, where he directs programs which seek to experiment with and create new knowledge on the structure of public and private institutions to accelerate the use of science and technology. Between 1972 and 1975, he directed the NSF's Office of Systems Integration and Analysis, and concurrently was director of the Office of Public Technology Projects and the Office of Experimental R & D Incentives. An employee of the Aerospace Corporation for twelve years starting in 1958, Mr. Wetmore directed the ASTEC Solar Energy Program, the first USAF communication satellite program system definition, and the Advanced Launch System Studies; he was also a member of the Ad Hoc USAF Committee responsible for definitive systems studies leading to the initiation of the Titan III Space Launch System. As an instructor at the University of California, Los Angeles, Mr. Wetmore taught courses in advanced propulsion system concepts.

Dr. Daniel C. Drucker
Dean of Engineering, University of Illinois

Let me review this diverse set of policy recommendations.

The recommendation to industry, but not necessarily to all industries, is to maintain a continuous physical presence at the university cooperative research center.

The recommendation to government is to foster interaction among industry, the professorial staff and the students on the campuses by funding that requires joint activity.

Another recommendation to government is to couple research and development efforts and, in the jargon of the trade, to use 6.1 and 6.2 money together, as far as one can, to enhance the interaction between research and development.

It is also suggested that government agencies pool resources: DOD, for example, can work through the NSF.

A recommendation to the universities is to bring the schools of engineering and business together to address, through educational programs, the education of students to participate in the process of entrepreneurship and innovation.

We recommend that the government use funding to bring the mission agencies into the technical picture in a knowledgeable way, when they are not the consumers of the research.

We recommend that there be brief seed funding to get things started when there is a high proprietary pay-off, and the withdrawal of federal funding as soon as the centers become operative. On the other hand, when there are industries that are fragmented, when the social gains are much greater than the gains achieved by the individual industries and when there is no prospect for sufficient financial support from those industries, one should consider federal funding on an indefinite basis in order to serve the public good. Such funding is to be, however, primarily in the area of fundamental research and not in the area of development.

It has been suggested that the models we hold in our minds may or may not correspond with reality, and that we should conduct a critical examination of these models: a simulation and study of the total system, including the economic, sociological and technical bases of our values or objectives, and the linkages between them and the programs that we devise.

We recommend that cooperative research centers be designed to complement the activities of private consultants and research institutes, and not to duplicate or interfere with these activities.

Our last suggestion is that we create proper attitudes through cooperative research. Even if the research itself is not that significant, the change in attitude might in itself be an important outcome.

BIOGRAPHICAL NOTE

Dr. Daniel C. Drucker has been dean of the College of Engineering at the University of Illinois, Urbana-Champaign, since 1968. Dr. Drucker's formal education was at Columbia University where he received a B.S. degree in 1937, a C.E. degree in 1938, and the Ph.D. in 1940. Prior to becoming dean at Illinois, he was associated with Cornell University, the Armour Research Foundation, U.S. Army Air Corps, Illinois Tech, and for twenty-one years served as chairman of the Division of Engineering and of the Physical Science Council at Brown University.

Dr. Drucker has authored one book, over 150 technical papers, and a number of articles on engineering and society.

A member of the National Academy of Engineering and the American Academy of Arts and Sciences, he is also Treasurer of the International Union of Theoretical and Applied Mechanics, a member of the General Committee of the International Council of Scientific Unions, and a past president of the American Society of Mechanical Engineers, the Society for Experimental Stress Analysis and other engineering groups.

Dr. Drucker has received the Egleston Medal of the Columbia University Engineering Alumni Association, an Honorary Doctor of Engineering degree from Lehigh University, and the Gustave Trasenster Medal of the University of Liege.

DISCUSSION

Jerry Weisbach: I think that the question of government support for proprietary research was mentioned twice. This is a well-established practice in Belgium, where an organization called IRSIA is set up to fund research. It is based on the principle of giving a company all of the patents and letting it keep all of the technology that results from the research, as long as it builds Belgian industry and provides jobs in Belgium. Full grants are awarded, and no questions asked! I am not sure that the attitude towards industry in this country even allows discussion of that kind of program. But it certainly works for the Belgians, and they and other foreign countries are running us into the ground.

Daniel Drucker: As you point out, there is a problem with the attitude of many people in this country, which must be faced.

Steward Flaschen: May I follow up that question, and ask the panel's opinion on the issue of financing innovation? After the engineers and scientists have done their job and done it well, this may be the greatest problem to the timely introduction of an innovation. The problem is not in financing R & D budgets, but in financing the capital budget, and it's as much a problem for universities as it is for industry. The capital budget can run from ten to fifty or more times the R & D budget, when the innovation would make obsolete a plant, production equipment or existing tooling. We are in an inflationary period, and the cost of capital for doing something new in a plant or a university is an extraordinarily difficult problem that can slow down, defer, and even postpone very good innovative ideas. Does the panel have some comments on that?

Dr. Drucker: We made a list of a few topics we thought should be explored but for which we did not have even preliminary policy recommendations. One of these is the capital formation question; another is the tax incentive issue. The third and last is the question of whether centers should be established in industries rather than universities.

Dr. Flaschen: The Japanese model is a very interesting one, in which the government and the banks have combined to make the cost of capital for innovation very attractive to Japanese industry.

William Wetmore: We did discuss various models. I think that we all have seen a lot of cases, several in detail, in which an industry has been analyzed and new, extremely attractive solutions have been found. However, as you say, the cost of capital and the need for new equipment precluded adoption of new technology. We have seen that many times in the textile and poultry industries. Over half of the protein consumed in this country now is from chicken, from poultry, and we need new industrial growth there. But the industry is getting highly automated, and hasn't got the capital to make the changes required.

Bill Buckley: I would like to come back to the scenario of research in government, university and industry. I harken back to the call for values, and the one term that has been missing or skimmed over which needs to be included is the word "freedom." This country was built on freedom, and those of us who are involved in research know the importance of the freedom to explore. Almost every research director in companies that I've talked to will say: "Well, our good work was accomplished because we were willing to hide it from corporate management." The academicians have said: "If a kid has an idea, he or she has got three years to finish it." We know that three years is a short time. The government hands out booby prizes for people doing exploratory work. We need to face this and face it very seriously, and I have a few suggestions.

I think that the NSF should reconsider a bit the decision to pull out of the Polymer Processing Program. It was a seeded operation and the seeding was good. This program is working, and the seeding function, which allowed things to grow freely without setting a lot of demands, provides freedom to explore.

My other observation concerns the critical importance of inflation. It is enhancing the three problem areas of greed, impatience and fear, and in doing so is affecting all of society. I think that the NSF could do a lot for research by focusing its attention on reducing inflation, which might include reducing funding of major programs -- we all know that it is all on borrowed money, anyhow.

John Thompson: You suggest that the Federal Government should chip in a bit more, particularly to the R & D centers. But from my spectator's seat I have noted that the total spent on R & D here in the States is just over $50 billion per year, greater than the total spending of either Germany or Japan. My question is, if ten times the amount spent on R & D is not enough to keep us ahead of the Japanese and the Germans, what makes you think that spending even more will do it?

Dr. Drucker: One of our difficulties, and perhaps one of our advantages, is that much of R & D funding is spent in the military sector. Spin-off has occurred and does occur, but it may or may not be helpful at any given time.

In justice to my compatriots on the panel, we really were discussing more "R" than "D". When you talk about "R," and especially "R" in the university sense, the amount of "D" is not really very large. To give you a rough picture of the paucity of research support in universities, in chemistry, for example, about one out of four university researchers is supported in this country through the NSF and similar agencies. In engineering, the figure is only one out of sixteen. My own assessment (I must not include the panel here) is that we suffer from a severe shortage of what one would call the fundamental information generated by research. The problem is not quite so acute at the engineering science level, but it is severe at the engineering subdiscipline level, which is still below where industry can easily pick it up and innovate on its own. Much of what we are discussing here in the cooperative research area is at that level of research; it requires cooperation to be developed and utilized.

Walter Abel: We see so much technology simply sitting there, which drives me nuts. I look at divisions which are not using the new, existing technology. That is why I have gone from one end of the spectrum right down to the other. I believe that we must get a base built on which we can better use technology.

Mr. Thompson: NASA, I believe, is currently sitting on something like 40,000 ideas, many of which have already been patented. But of all these, barely two percent have been exploited by anyone. They are all sitting in files somewhere, and most of them are jolly good ideas.

Dr. Drucker: Again, this is the wrong end of the spectrum. As David would tell you, it does not do me any good to invent something for you to use. However, it does do you good if basic fundamental information is available for you to pick up and use. It depends upon the industry, of course. But once something is invented, the question of whether it is then worth exploiting is a very tricky commercial point.

Marvin Goldberger: Why must we have a Cooperative Auto Research Program at this time?

Howard Dugoff: Well, I thought that I answered that question in my prepared remarks, but I will try to reiterate what I said, and perhaps you can draw me out if it does not do justice to the question.

There are three premises. It is an article of faith in the rationale for the CARP program that the enhancement of the base of fundamental knowledge in the engineering subdisciplines related to the technology of the automobile will ultimately lead to advances in that technology. That is premise one. The second premise is that advances in the technology of the automobile will be socially beneficial, especially in the areas of energy conservation, environmental protection, safety and the other attributes of the automobile that make it so attractive a vehicle for personal mobility. It is fair to say, however, that energy conservation is the driving consideration at this point. Third, the reason why we established the Cooperative Program, rather than just beefing up existing NSF support of those engineering disciplines, is that the involvement of the ultimate developer and the government agency responsible for policy in that area is beneficial from an educational standpoint.

Dr. Goldberger: I am disturbed that this very strong, powerful industry cannot do this by itself. Why not?

Mr. Dugoff: History proves, I think, that there is not sufficient motivation from the marketplace to advance fundamental scientific areas. There is no first-order commercial benefit for any one of the automotive manufacturers in funding work in the basics of tribology.

Dr. Goldberger: You do not think that the thirty percent import of Japanese cars mentioned this morning might be somewhat of an impetus?

Mr. Dugoff: No, I do not. I do not believe that it makes sense, from an industrial perspective, to attempt to fight the tide of imported automobiles by increasing the funding of university research in the basics of tribology or control system theory.

Dr. Drucker: There are two separate questions: one asks whether the research is needed, quite apart from who funds it. The answer to that is a clear yes. The body of knowledge, which I have called the engineering subdiscipline, does not exist. As a physicist by training, it may be difficult for you to appreciate that the amount of effort one needs goes up as he moves towards the development side of the picture. The amount of effort one needs in basic science is so high, in what we call engineering science is much higher, in the engineering subdisciplines it is ever so much higher, and so on. But the relative effort in this country in these areas has been the inverse of what is required. Although still more is needed, there is much more funding of basic science than there is of engineering science, and more funding of engineering science than of the engineering subdisciplines. There is, of course, a large amount of funding in development. But funding development alone does not work without that background of knowledge, which simply does not exist.

Now, the question of why the automotive industry did not produce that body of knowledge is a very good question. But the fact remains that the body of knowledge does not exist.

John Bilello: A number of the speakers during these past two days have considered the stability of funding, job security, etc. Others have mentioned seed money, which is phased out over the course of a program. Having lived through Center of Excellence Grants and things like that, I am very suspicious that the two are compatible. I assume that you want to attract the very best and brightest people, for whom universities and industries will be in competition. How can you have stability of funding and job security and dedicated people, giving them that kind of loyalty toward their institutions (which is apparently fairly strong in Japan) and at the same time phase programs out and use seed money for new ventures?

Mr. Wetmore: An example of stable funding is the Polymer Center here at MIT. There was a five-year award granted all at once in 1973. This commitment provided stability. We have done that in other cases, and we are continuing to do it. I think that stability of funding is healthy, and indeed essential.

The second point you raised concerned seed money. In general, as time passes, we would like to see the federal funds decreasing while the commitment from industry and university is building. In some cases it has not happened. It did here at MIT in a high-technology area, but it did not at North Carolina State University with the furniture manufacturers. We agree that seed money can catalyze a program, leading to a gradual decrease in federal support.

Dr. Bilello: One of the gentlemen mentioned some of the reasons that he did research overseas at a number of universities. Every one of those universities has had technical support in institutes for a hundred years. In this vein, I have not heard anyone discuss the EPRI model. Why not?

Dr. Drucker: We did not talk about the EPRI model, but of course it is something like the automotive model. There was external pressure applied; in the case of EPRI, through a tax proposal by Magnuson. The EPRI model was not a voluntary model. It was a defense by the industry against the government, which is all to the good. We would welcome other imitators of EPRI. To a certain extent, the automotive initiative builds on the EPRI model with joint funding of research at universities by the automotive industries and government.

Richard Cyert: I want to make a few comments on the interchange between Dr. Goldberger and Mr. Dugoff. The role of government is to intervene when the private sector cannot capture completely the benefits of a piece of research or a particular action -- in other words, when there are externalities present. In that case, society has a stake and should be contributing some of the funding.

The second point is that when we are interested in eliminating some of the aspects of pollution, or in producing automobiles with better mileage, it is possible for society to act as it has and devise laws so that some of the cost which might be external and borne by society is borne by industry. In this case, industry does have great incentive to go ahead and operate individually. The only justification for the government's having a program like CARP is that the society is interested in developing new knowledge about automobile engines that will be shared by all companies. In this way, the research may develop faster and the new knowledge will become available to everyone faster.

PANEL IV: Summary Session

Participants:
Dr. Marvin L. Goldberger, Chairman
The Honorable Wes Watkins
Dr. Edward E. David, Jr.
Dr. John H. Gibbons
Dr. Richard M. Cyert
Mr. Norman L. Greenman

Dr. Marvin L. Goldberger
President, California Institute of Technology

This conference has been so far pretty much a love-in; everybody here believes in cooperative research. Only Professor Noble yesterday had the temerity to raise some heretical questions, as referred to by Dr. Hansen. Is there an implementation gap? If so, is that what is causing the drop-off in productivity?

I am concerned about one aspect of this otherwise beautifully organized conference. That is the absence of certain interest groups that I think would and should have been here, because they all have a considerable involvement in industry, university, and government research activities. As far as I know, there is no representation from the areas of computer science, chemistry, biology, geology, economics, enterprise and public policy. One other observation: there is an extraordinarily small number of women in the audience. That is a problem that all of us in technical universities are tremendously concerned about, and I gather that the problem must be equally severe in the technical industries and that there are very few women in higher management levels.

Historically, there has been a considerable fear in the academic community that federal support of research in universities would lead to the loss of what is sometimes called "academic freedom," and would force growth in those universities in the areas that received the largest amount of research money. There is a tendency to go where the money is.

There were, fortunately, some examples of extraordinarily enlightened government agencies after the war that began to fund research. Noteworthy among these was ONR; another was the Air Force Office of Scientific Research. I once had a contract at Princeton that was entitled "Fundamental Aspects of Theoretical Physics;" you couldn't ask for much more freedom than that.

I think that, on the whole, these agencies have done an extraordinarily good job. President Wiesner yesterday commented about the fact that there has been some tendency in recent years to say that you have a certain quantity of money, and that this is divided up in a relatively uniform fashion. This has caused some criticism because "elitism" is considered a bad word. But, be that as it may, government-supported basic research has been a tremendous success by any measure. It is probably worth noting that one of the reasons for the enthusiastic support of research in the sciences was the smashing success of the scientific community in World War II. No matter how much we protested to Congress that a 500 GEV particle accelerator had nothing to do with building weapons, they would not believe us. Unfortunately, I think that they are now beginning to believe us.

Now, as we contemplate a greater involvement between industry and the university, I think we have to pay attention to some of these issues. Support of basic research and education is regarded as a public good. That is one of the reasons why the government is prepared to support these. It is not at all clear that industry as a whole feels the same way. We have been concerned here about the advantages that might accrue to industry and to the university and ultimately to the country by increasing cooperative university-industry interactions. I have considerable concern about the impact of this increased collaboration on the traditional role of the universities, which has always been the creation, storage and transmission of knowledge. If I were completely convinced that they were a good thing, and I am not as yet, I would personally approach something like Mr. Haynes' Cooperative Generic Technology Centers with some caution on our campus because of the effects that an effort of the contemplated size of the centers might have on a small institution. I can see ways in our own particular case, because of the presence of the Jet Propulsion Laboratory, that I might be able to work it. But these centers at universities may very well not be everyone's cup of tea. We must not lose sight in the universities of the need for the single-minded and relentless pursuit of basic science. Maybe the most effective way we can contribute to industry, to national defense, and to the welfare of the country is to concentrate our efforts on producing the very best trained people that we can. We must provide a broad enough exposure so that our students can move freely into industry, into law, into medicine, into a whole variety of subjects, and not be forced into a particular mold to make them peculiarly useful for industry. The universities have been an extraordinarily successful institution in this country, and I think that when we tamper with them, we are taking a chance. I am not arguing for the status quo; universities have to change like other institutions, but they should change carefully.

I want to close my remarks by skimming a few comments from a recent article by Lewis Thomas that appeared in that obscure journal, the *New England Journal of Medicine.* Lewis Thomas, whom some of you may know, is a very wise and thoughtful man who has written some beautiful books. He argues that there is some danger that we are not depositing enough new information in the research bank in our efforts to meet current-day societal problems. Even in the kinds of research that are properly classified as basic, the expectation is that short-order results can be obtained. If it looks as though they will not come quickly, the research tends to be put aside, because we have got to write a grant proposal for the next year's support. It is Thomas's feeling, and I agree with him, that there is no longer the driving force in the scientific enterprise that there was during the productive 1950's and 60's. No one in the community of working scientists or in the bureaucracies governing the support of science is willing to run the risk of being wrong. If things go on this way, the country's basic science efforts will come to a standstill and the bank will be empty. Finally, Thomas says, "...perhaps the industrial community should step in now before it is too late and assume their share of financial responsibility for the future of basic science," and he puts in an aside: "...not just biomedical science but science in general, not philanthropy, not any sort of noblesse oblige." Nor does he suggest that the amount of money should be anything like the scale of support for science that comes from the Federal Government.

I personally feel that about two percent of corporate profits would not be an unreasonable amount to contribute to the broad support of education; not just science, but education throughout the country. I think it is important that we explore new mechanisms for the involvement of industry and university. For my own institution, these interactions are much more likely to come on a person-to-person basis. Usually, there is a need for work recognized by someone in an industry who becomes aware of a particular line of research that is going on in chemistry or biology. We have examples of this where we have a fruitful collaboration already with industry.

"Center" tends to be a dirty word around Caltech. It is not a dirty word around MIT. I think there are twenty-three centers of one sort or another at MIT, so I am presenting you with a somewhat contrary point of view.

There are problems which have been underscored, and I hope will be brought up further in questions during the discussion, having to do with patents, proprietary rights, traditions of secrecy and the desire on the part of the universities to publish their results instantly. All of these have to be dealt with. As I commented yesterday, at least in one case, in our Silicon Structures Program at Caltech, all of these problems have been disposed of. And I think by working together and thinking about them we can have an effective marriage. But there will be different models for different institutions.

BIOGRAPHICAL NOTE

Currently the president of the California Institute of Technology, Dr. Marvin L. Goldberger has been very active for many years as an advisor to various government agencies on national security affairs. He was one of the founders (in 1959) of the Jason Group, originally associated with the Institute for Defense Analyses and now with SRI International. This group of about thirty-five, composed mainly of physicists, works for the Department of Defense and other agencies on both classified and unclassified problems involving advanced technological concepts. He was a member of the President's Science Advisory Committee from 1965 to 1969 and a long-term member and ultimately chairman of its Strategic Military Committee. He was chairman of the Federation of American Scientists during 1972 and 1973, and a member of the Ford Foundation - Mitre Corporation study, Nuclear Power - Issues and Choices.

Dr. Goldberger has been heavily involved in international scientific affairs. From 1963 to 1969, he was chairman of the High Energy Physics Commission of the International Union of Pure and Applied Physics (IUPAP) and for several years was a U.S. representative to IUPAP. In May 1972, he headed a scientific delegation to the People's Republic of China which arranged for the first visit to the U.S. of a group of Chinese scientists in December 1972. He returned to China in July 1973 as head of a delegation of U.S. physicists.

He is the author of about 150 scientific papers on a wide variety of subjects in theoretical physics: nuclear physics, plasma physics, theory in intensity correlations, reactions among elementary particles at high energies, S-matrix theory and quantum field theory. He is best known for his work on the theory and application of dispersion relations to problems of weak and strong interactions and for his monograph (with K. M. Watson) *Collision Theory*.

He is a fellow of the American Physical Society and currently vice-president elect, a fellow of the American Academy of Arts and Sciences, a member of the National Academy of Sciences, and a member of the Council on Foreign Relations. In 1961, he was awarded the Dannie Heineman Prize for Mathematical Physics.

Dr. Goldberger received his Ph.D. in physics from the University of Chicago in 1948 and is the holder of two honorary Sc.D. degrees from Carnegie-Mellon University and the University of Notre Dame.

The Honorable Wes Watkins
United States House of Representatives

I would like you to know that I am a businessman who went off to Congress. Before I was a Congressman, I was a frustrated businessman; now I am a frustrated Congressman. I am from rural America, from small cities and rural communities. Big industry was not there to help us when I grew up, but that trend is reversed now. The government has done much to provide assistance to rural America.

A gentleman earlier talked about freedom, and I know exactly what he means when he talks about freedom. Tax freedom, regulation freedom and other areas must be addressed if we are to increase productivity. Another question was, why do we want to spend? Could it bring better results? It depends on how the money is spent. I am a businessman and I believe in investments. Much of the technological information that this country produces yields six dollars return for every dollar invested. That is good business. Some of the technology transfer produces thirty dollars return for each dollar invested, and that is good business.

Dr. Goldberger mentioned certain groups that were absent from the conference, and I would add one other group, the small businessmen. Small industry is absent. Fifty percent of the major new inventions come from small businesses. What does that say about our universities and the major research and development divisions of our major companies? Maybe there should be more dollars from the government going into innovation centers that would become the R & D divisions for small business and industry. An old saying that I learned on the farm a long time ago goes, "A crisis is the mother of invention." If you are out there on the firing line, you start looking for a better way to build a mousetrap.

I suppose that if I had to title this address, it would be "What is Innovation?" We know where we are going; we are trying to decide how to get there. I serve on the Science and Technology Committee in the Congress. Overall, I think that the outlook for cooperative research and innovation is great. There is discussion taking place here in America about the need for cooperative research and innovation. You may not hear those terms, but you hear the public talking about double digit inflation, the balance of payments and the record-breaking deficit that we had last year. You hear the public talking about the fact that productivity is way down in this country. The public is clamoring for action.

You may be wondering why a Congressman from rural Oklahoma is here. I am from a rural, economically depressed area. I have devoted my adult life to building job opportunities. There are two ways to build jobs. Maybe your plant or industry is expanding. Many times industry will not go to a rural area that is depressed, with boarded-up windows and grass growing in the streets. The company presidents say, "No, we can go into 10,000 places where there are industrial parks to locate industry." Sometimes the government is willing to do more than industry to get a region on its feet; and in some areas government help is necessary. But there is a second way to build jobs. That is through innovation: giving birth to industry, if you please. I believe this is very important. You must answer two questions: is it technically feasible to build that new product, and is the product marketable? If you answer those two questions, and mix a little management and financing with it, you can get out there behind that empty, boarded-up building and start growing. Ninety-four percent of the people who left my area in the Okie-Arkie westward migration right after the Dust Bowl said that they would return if they could find a comparable job back home. But they cannot come home because there are no jobs. Eighty-five to ninety percent of them go off to college, but only four percent of those with educations return. The rest cannot come back. That is why I am interested in productivity and jobs.

Congress has formed an *ad hoc* Task Force on Industrial Innovation with twenty-four congressmen as members. Not long ago we had a colloquy in the House on national TV by satellite. Twenty congressmen participated in a discussion about productivity and the need for innovation. The House Science and Technology Committee, on which I serve, and the Science and Transportation Committee have held extensive hearings, examining the barriers to innovation and the need for changes in public policy to promote cooperative research. We have prepared several pieces of legislation that I will mention later. I am optimistic, but Congress already has a crowded calendar. It is election year and we have to go back and be reelected -- unfortunately, I have to run for office every two years. You cannot expect a lot of legislation coming out this year, but I would like to discuss the specific legislation for innovation.

First, I would like to talk about the President's Innovation Initiatives that we funded in the FY81 budget. These include approximately eight million dollars for three new Generic Technology Centers in the Department of Commerce (DOC), and an additional $2.6 million for at least one generic center and one or two major technology innovation projects within the NSF. Ten million dollars was appropriated for small business innovation, and almost thirteen million more for NSF's industry-university cooperative research program. These are not all new programs;

some were already funded in FY80, but there are major increases in some areas. We will probably authorize some of these programs and we will probably offer a little more direction in the area of small business innovation. I will probably be asking the NSF, and may even propose amendments, to set aside some block grants for innovation centers so that small businesses can work with them. Most small businesses do not even know that they can go to the NSF for help, certainly not in my part of the country. Sometimes a small businessman is overwhelmed when he tries to work through one of these things. When he tries to get through to Washington and back, he usually just gives up. But if we had the block grant within an innovation center, small businessmen could come and sit down with the engineers and researchers and technicians. Innovation centers can stimulate these proposals. Most of the money that the NSF is asking for can be justified, and I think that the authorization process will leave it intact, subject to trimming in the appropriation process.

President Carter also established the Corporation for Innovation Development (CID); one in the urban area and one in the rural area, patterned after the Connecticut Product Development Program and Great Britain's National Research Development Corporation. They would loan seed money to help develop new products or processes. The Commerce Department set aside $750,000 in FY80 for each one of these, and projects funding of at least $2,000,000 for each of them in the 1981 budget. I predict that the money will be there.

President Carter called for changes in patent policy which I think represent steps in the right direction. There are several patent bills pending in Congress. The cloakroom talk is that Congress will pass the Dole-Bayh Bill in the Senate, a watered-down version of what the President seeks. It provides patent ownership, but only to universities and small businesses which develop patents as a result of federal R & D contracts. This bill has been reported out of Senate Committee and is currently pending before the full Senate.

The House Science and Technology Committee will be considering the Erlel bill, which is more in line with what the administration is requesting. The Erlel bill is similar to Senator Schmitt's bill in the Senate, and would allow all federal R & D contractors to keep patents to any discoveries made in the course of R & D projects. The Science and Technology Committee will report out the bill this spring. However, we are going to have trouble in the House because windfall profits are a big issue and some people think that this bill results in windfall profits for industry.

I would like to mention a piece of legislation I introduced that might be of interest, the Domestic Technology Transfer Act. We spend about $30 billion for basic research in this country. Most of it does not have to be justified in terms of how it will benefit the public. As a businessman, I always want to know how that dollar is going to be returned to the public. If the bill passes, we will mandate a technology transfer program whereby federal labs with 200 or more employees will be required to have one person dedicated to technology transfer, who files a technology transfer impact statement for the laboratory's research. Some people might not like that particular phase of it, but I think that it is necessary. That legislation will be introduced later on.

Congress is sensitive, concerned and working to increase productivity. I know as a businessman that if we can get tax and regulation relief we can put more money into research and development. But R & D does not exist in rural America. That is why I am working for small business to acquire an Innovation Center. We need to start new industries in rural America.

BIOGRAPHICAL NOTE

Congressman Wes Watkins, Oklahoma's Third District Congressman, began serving his first term in the U.S. House of Representatives in 1977 with the 95th Congress. He was re-elected without opposition to the 96th Congress, becoming the only Oklahoma freshman congressman since statehood to be unopposed for a second term.

A native of Oklahoma, the Democratic congressman has turned much of his attention to rural development and getting fair and equal treatment for small towns and rural areas. He was elected chairman of the Congressional Rural Caucus for this Congress, moving to the CRC's top post after only a year's membership in the organization.

Congressman Watkins is serving again this Congress, on the House Committee on Banking, Finance and Urban Affairs and the Committee on Science and Technology, assignments he first drew in the 95th Congress. He also has been named to the House Select Committee on Aging and was elected Majority Zone Whip for the States of Oklahoma, Arkansas and Kansas.

Prior to his election to Congress, Mr. Watkins owned and operated a homebuilding firm and real estate agency in Oklahoma. He also served as a member of the Oklahoma State Senate and as president of the Higher Education Alumni Council of Oklahoma and has been active in civic and community affairs for a number of years. In 1968, he was named one of the three Outstanding Young Men in Oklahoma by the Jaycees.

In 1978, he was awarded the national Future Farmers of America Honorary American Farmer Degree, the Oklahoma 4-H Alumni Recognition Award and the National Federation of Independent Business "Guardian of Small Business Award" and was recognized by the Coalition for Peace Through Strength with a "Leadership Award." In 1977, he was recognized by the Oklahoma State University Alumni Association with its Distinguished Alumnus Award.

Mr. Watkins completed his undergraduate education at Oklahoma State University, where he served as president of both the student senate and the student body, as state president of the Oklahoma Future Farmers of America, and was named outstanding agriculture student. He received his master's degree from OSU in 1961.

DISCUSSION

Marvin L. Goldberger: The members of the panel have graciously agreed to forego their voluminous prepared statements so that we may have more time available for discussion with the audience. They may occasionally turn to each other and ask questions of each other, but we will now open the floor for discussion.

Robert Colton: I would like to challenge the proposition that basic research in itself is something that has no important proprietary needs as far as business is concerned. I think that the government emphasizes possibilities of investigations in basic research because it believes that this is one area where no one needs protection.

I have examined a number of patents in the area, and have realized that probably the most important and widest range of patents in the U.S. are the result of basic research. Therefore, I would like the panel to discuss the pros and cons of the government defining basic research as something that no one really wants protection from, when in fact this may not be true.

Edward E. David, Jr.: Basic research produces the most fundamental patents, and, in addition, the follow-on patents after the fundamental ones constitute a portfolio supporting entire technologies. So, I agree with Mr. Colton that basic research is a good source of patents, and I also agree that the definition the government uses for basic research seems to miss the point. The NSF's definition of basic research is based on motivation; if you are motivated to applications, you are not doing basic research. If you are motivated toward the extension of knowledge, it is basic research. This definition cannot be sustained. It is very difficult to tell the difference between the motivations of the researchers in the basic laboratories of industry and in the basic laboratories of universities. Yet, in the basic research labs in industry, the objective is obviously commercial. So I do not think that a definition based on motivation will stand up. The definition really should be based on whether the research is done in a scientific way, and stands a good chance of establishing new knowledge. If so, it can serve as a bench mark, a base for further research. I think we would be in a much better situation with respect to policy and funding if we adopted this definition.

Speaker not identified: The increased freedom in grants is part of the same problem. There has been a relaxation of the requirement to specify how the research support, the grant, will be used. The fact that some research leads to a patent and that someone might benefit from that is not a problem from the standpoint of supporting basic research, because great benefits to the society as a whole also come out of this research.

Secondly, what we want in this country is a portfolio, similar to what a good university has. There should be a portfolio of problems which includes some with long-term potential payoffs and some with short-term payoffs. The tendency of government, under the pressure of specific problems in society, is to move towards more and more short-term payoffs. We must have a balanced portfolio, and have the self-discipline to spend more time on that portion of it that we would call basic research, the kind of research that is designed to satisfy curiosity.

Rein Narma: One of the concerns that I and many in our industry have is that additional government funding of various research and development programs will further aggravate a problem that is already serious in the electronics industry. Most of our R & D programs today are limited by a lack of human resources. We do not have a sufficient number of well-educated engineers and scientists. It is rarely the dollars that are lacking today in our industry; it is the human resources. Could the panel discuss this issue?

Dr. Goldberger: I made some reference to the fact that perhaps the most effective way we could contribute to the research health of the country, the industries and the national security, is by training people. Give us the money and we will train the people. But it is also very important for the university to become directly involved with industry. The connections that the industry-university associations build up must endure long enough to make them meaningful. There is a degree of longevity and stability which is very important in maintaining the proper educational aspect of the collaboration. I think that any university is out of its mind to go into an involvement with industry that does not have a strong educational component to it.

Speaker not identified: One of the things that tends to be ignored is the fact that we allocate resources in this country on the basis of a price system, and that entrances into engineering schools are particularly sensitive to the price system. There has been an analysis of the market for engineers by Richard Freeman of the Harvard economics department. He found a very high correlation between the number of students entering engineering schools in the country as a whole and the salaries of graduating seniors in engineering. So there is not a danger that putting more money in will bid up prices; it will increase the supply. I think we have to remember that the so-called shortages are really periods in which you have to pay more for people, and that this, in turn, generates new people. But we must realize that these people are often not used very well in industry. I know, for example, of one large laboratory that has sixteen Ph.D.'s and no technicians. I know of any number of laboratories where engineers spend a large part of their time shuffling paper, attending to unnecessary reports, and protecting themselves from having their budgets cut by people who do not understand what they are doing. I would strongly recommend that all of us who complain about the engineering shortage look at our R & D and engineering departments, and improve the utilization of our people. I think that we are sadly underutilizing them and are missing a great opportunity to take advantage of what resources we have.

Dr. David: Herbert Holloman made a study similar to Dick Freeman's, which showed that the system is indeed very sensitive, and because of the four-year time lag it is oscillatory. This is a rather disturbing situation: if there are very large inputs at any one time, such as would be created by the CARP program and some of the other proposals that have been made, there will be a tremendous flow of engineers. Then, at about the time that those engineers show up, they will not be needed. There will be an oversupply, everybody will drop out of engineering school, and four years later there will be a shortage of engineers again. This has happened several times before.

John Thompson: There is a piece in President Carter's innovation message concerned with information, and in it he proposes two things. One is that the activities of the National Technical Information Service be expanded so that the data base would include whatever can be picked up about foreign technology as well as American technology. Secondly, he proposes setting up a kind of voluntary check-point-Charlie, where American business people returning from abroad with their notebooks and cameras would check in and divulge all of the secrets they had learned. Would any of you like to explain how you see these two things operating in practice?

Congressman Wes Watkins: The first proposal mentioned has been discussed in several Congressional committees. The second, the check-point-Charlie, started last week with ABSCAM.

Albert Broll: I found the conference here very stimulating and sometimes very confusing. I hear from some people that there is a creativity crisis, and from others that there is not. I hear that we ought to apply our energies towards fundamental research, and in other cases towards applied. It strikes me that the government is looking at society and seeing two problems.

One, foreign companies are coming in and getting a greater share. Two, academic institutions are facing a fiscal problem, or at least a coming problem, in terms of the population drop and the inflating cost of education.

There are some things that have been made very clear, I think, during this conference. One is that government is out there and dangling money and it wants to help. It is clear that academic institutions are also eager to be helped fiscally. Some very large industries are saying, "We have all of the knowledge and invention that some of the foreigners seem to have, and we too could have achieved what they have achieved, but we have not." A lot of businesses are saying, "The problem is really not in creativity from the fundamental standpoint, but in the innovation process and the conversion into products; the problem is in the cost of that whole process."

In the setting up of institutes to bring together industry and academia, it is clear what the benefit to academia might be, and I think that some of the problems Dr. Goldberger mentioned can be guarded against. But it is not clear to me that the real problem, that of putting new products on the market and improving our competitive edge, is really going to be affected by cooperation. I think that there is real value in these centers, in industry getting more closely aligned with academia, but I am not sure that this will affect the innovative process. If government is interested in helping here, it shouldn't propose plans without really looking at the basic problem. Government has made an assumption here that I am not sure is correct. If you ask industries why they are not out there competing, I think they know the answers. They know why they do not have a competitive edge. I am not sure that their answers would point to problems at the creative end. Before we move too far, we have to stop and get to some of the basic questions.

John H. Gibbons: I think you are right on target. We have had a strong focus on the "tech-fix" approach to improve innovation. Yet, as Tom Mathues and Ed Roberts and others have pointed out, technological innovation, if it is going to be successful, involves a lot more than just idea generation. It inherently contains a whole sequence of events. If that is the case, then it seems essential not to limit public investments to fostering technical invention. Rather, funds should be directed to help overcome a number of other constraints that are operating in the system -- constraints that are external to the normal market. These include high inflation rates, which cause one to focus on the near future and to be very conservative with capital. We need to overcome the paucity of rewards for taking risks and succeeding. We need to be careful about regulatory burdens, especially those that work hardships on people with new products or small businesses. Many nonmarket factors, such as public policies, introduce an uncertainty into the future that causes a lot of people to simply not take innovative risks. If we are going to talk about public investments in this area, the emphasis should be on ways to overcome these constraints to successful innovation and investment, not just on the development of technology per se.

Dwight Baumann: There has been an underlying theme to this conference on cooperative research: that it takes a specific person to make something happen. I like Daniel Drucker's idea that we have three groups: those who make things happen, those who understand what happens and those who wonder what happened. I suspect that we have only about one percent in the first category of people who make things happen, and that we need ways to create two percent. At the turn of the century we had a society that was enamored of the American entrepreneur. The Tom Edisons and the Henry Fords were in every newspaper. And so we replicated them or we tried to replicate them by institutionalizing a thing we called the School of Engineering. It worked out fine until after World War II, when we found that there was not quite enough civilian industry, so we created another kind of institution called the Business School. Now, we had Wharton and Harvard; but at places like Carnegie-Mellon we tried to train engineers in the art and science of management. We put a bandaid on the shortcomings of the engineers. The engineer was good at products, but he was no good at finances or marketing. So we put that bandaid on our system to produce these people who make things happen. I think we are about to see another bandaid, or another institution, developed -- the Innovation Center, the maternity ward where companies can start. Is this the missing ingredient?

Innovation or entrepreneurship requires three or four kinds of creativity: a creative product, a creative way to raise funds and a creative new marketing approach. You cannot get money without having a new idea about how to get it. You cannot go to the market with the same idea. There is another dimension of creativity, which in the political arena we call "charisma." This is necessary, also, in the technological and the enterprise areas, where it is called "leadership," corporate leadership. As we add this ingredient to our institutions, and try to prepare people in these four dimensions, perhaps a new kind of institution is evolving.

The kind of institution that we are beginning to understand how to evolve is an incubation center. We actually create the environment in which innovation can develop, in which the fuzzy thing that happened on 128 or in Palo Alto can be put into a format and aided in the same way that eggs are hatched in incubators instead of by hens. We need a method of nurturing and bringing together the ingredients of creativity in the four dimensions I mentioned.

Speaker not identified: I have two points that may be worthy of discussion by the group. First of all, the amounts of money being talked about at this meeting seem relatively piddling, including the $150 million that has been cited. We are talking about saving the lifeblood of the country, our balance of payments, with three million here and two million there. I am not even sure that these amounts of money are not simply the result of shuffling limited resources around: taking money from some basic university programs to do something more stylish (namely, technology transfer) with it. Are we really putting more money into training and research, or simply shuffling the cards in a different way?

Speaker not identified: I think that if you account for the inflation rate, we are just shuffling money around. It looks, just in terms of the units, as if there may be more dollars. But if you look at it in terms of what can be done with the money, basically we are starving some programs to feed others.

Dr. Goldberger: In connection with that, there is a great move from a number of quarters to establish individual, free-standing, basic research institutes, quite different from the centers that we are talking about. I have been a strong opponent of those things for a variety of reasons. In talking about the money aspect, I am very concerned about the diversion of funds from research in universities. When these research institute programs are proposed, we are always told by program managers in various nameless government foundations that they will be funded with new money. But anyone who believes that down the road, when push comes to shove, these programs will be supported with new money, also believes in the tooth fairy. It is going to come out of somebody's hide. So I think that your question is well posed.

Speaker not identified: Again, we are talking about relatively small amounts of money to help industry do its thing. At the same time, greater demands for money are being imposed on industry in the form of regulations or totally unconstructive tasks which the Japanese and the Germans do not really have. The parallel made yesterday between us and the Japanese and the Germans was not apt, in that they have a national purpose of improving their science and technology, while here we perceive the government as a decided adversary doing all it can to make life difficult. In the U.S., we are praying that we can win in a competition that we ourselves are making more and more difficult. If the government simply let us have the funds which we feel are being wasted (and not all of it is being wasted) for use in innovation and technology with the universities, the amount of funding that the government is providing would be totally unnecessary.

Congressman Watkins: I understand what you are saying. As a businessman who has gone to Congress, I share those frustrations. If it could get some tax relief, I think industry would be able to put a lot more money into research and development.

Also, the number of regulations are incredible. Many of us did not count on these problems when we passed, for example, the Clean Air Act and the Water Quality Act. We find ourselves taking these regulatory costs out of our overall budget. So, we take it out of R & D. The Windfall Profits Tax on oil is an example. U.S. industry will say that they will put more money back into drilling for more domestic oil, but we cannot do that.

Speaker not identified: At the moment, by the way, if a bright kid really wants to succeed he or she does not become a scientist or even a doctor, but an accountant or a lawyer, because the biggest growth industry is in dealing with Washington. There are statistics on this -- if you really want to make big bucks, that is the way to do it.

Congressman Watkins: Over fifty percent of the accounting graduates in this country go into government.

Lamar Bullock: Yesterday we heard about a key figure in bridging the gap between innovation and putting the product in the marketplace: the designer or the design engineer. We all know that if you play cards with somebody who is a talented shuffler, the cards come out the way he wants them to. Our goal is to find some way to get the cards to come out so that we can create more design engineers, and shift some emphasis from the engineering science back towards the technology. How can we use a cooperative synergistic program to graduate more students who really know how to design products for the marketplace?

Dr. Goldberger: There is a company in Cleveland by the name of Eaton. They have instituted a program, and several of these are going on at Stanford Engineering School, which precisely involves the actual design of an object as part of the curricular program. That seems like a reasonable way to go. I do not know how effective the graduates are, but it sounds like a good idea.

Richard M. Cyert: In education we do not have the fundamental experiments and data to say, "This is the way to proceed; if you do A, B, and C, then your outcome will be X." There is some interesting experimentation in various engineering schools. For example, at Carnegie-Mellon our Design Research Institute is making use of the artificial intelligence work which has been done with computers, and is combining it with some work on optimization techniques from operations research. From that combination, several computer programs for the design of chemical plants have been developed. I do not know whether this training can get down to specific kinds of products, since most of this research has been in process design. However, I would like to see a number of schools experimenting with different approaches. At Carnegie-Mellon, we are sensitive to the problem; the question is in finding the right educational technology to achieve the end.

Speaker not identified: There seems to be some fear on the part of the participants about the universities being involved in creating products.

Dr. David: One thing that has come out in our discussion is not that we are lacking in science and technology as much as we are lacking in design. I think that Marvin Goldberger asked this morning, "What is wrong with the U.S. automobile manufacturers?" I would not pretend to answer that, but certainly one difficulty is that their designs have not been as appropriate for the times as those of the Japanese and German companies have been. There have been attempts for many years to get design into the engineering curriculum. Myron Tribus, who is here at MIT now, is one of the people who tried innovative design programs at UCLA and later at Dartmouth. There have been other attempts over the years, and I would say two things about them.

One, if there was anything missing in these efforts it was not the scientific or the technological basis for design, but the artistic basis for design. There is a very strong element of art in putting together a good design; it is a creative activity.

My second point concerns the industrial side. Industry has not provided the incentives, the money, to encourage people to go into design. We have not pointed out to students that there is an artistic side to design and that there can be a great deal of satisfaction in creative design. It is not just a matter of sitting down and painting a sketch on a cathode ray tube. If we encouraged the artistic touch in design and made it a prestige occupation in industry, while not ignoring its scientific basis, we would cure the problem.

John Bernard: I have been sitting here for two days listening to discussion about forming these various complex centers to help redress a basic balance. We have seen industry shift away from the universities and we feel we need industry to shift back to universities; not to negate everything else that we are doing, but just to try to move back a bit in the other direction. I think that there might be much simpler ways of doing this than many of those that have been suggested in the last two days. One way is to have industry work individually with the university, through some kind of partial financial incentive like tax incentives. This was discussed at length in the President's DPR, which I happened to be a part of, but never got through the maze of recommendations. It is a very simple mechanism to achieve the objectives for which everyone has been proposing very complicated mechanisms. It has the advantage of a diversity of industries seeking the help that they feel they need. They would put up a substantial part of the money themselves, individually, to work with the individual universities of their choice. It gets the government completely out of it. I believe that this freedom and this multifaceted approach to the problem are a lot better than taking that same money and dumping it into several big technology centers.

Speaker not identified: There is a bill in Congress introduced by Congressman Vanik that will do approximately this, although I do not know the magnitude of the proposal or its details. Is it similar?

Speaker not identified: Yes, it is very similar.

Dr. Goldberger: I think that this idea of tax credits, which is in the Vanik bill as I understand it, is very important.

Dr. Gibbons: I would like to return to this notion of packaging. It seems to me that one simple way to go after this is through co-op programs, which are certainly very successful interactions between industry and universities. Why not design those co-op programs so that an engineering student is exposed not just to one discipline within the industrial setting, but also to people doing market analysis? It is the engineering *and* marketing that produce the successful products? I think that the Japanese have been eminently successful in combining innovative design and engineering with smart marketing strategies.

Marvin Margoshes: I want to comment on two things. First, the question was asked a little while ago, "What is in it for industry?" Technicon's Research Grants Program has run for several years now. It is just about five years since we awarded our first grant, and I can only point to one product that has come out of this. But considering the failure rate in research and development projects, and the long lead time for product development, five years is a rather short time. My management is convinced that it is a worthwhile, effective program, and I think that the procedures we use have proven to be effective and can probably be adopted by other companies.

Now, on the negative side: I do not think that Congressman Watkins intended to hold a hearing on his technology transfer bill, but I would like to say a word about it. There is already extensive government effort in technology transfer to make available what has come out of government laboratories or government-sponsored research. NASA publishes a rather thick booklet four times a year, and the Department of Commerce publishes a number of booklets -- one of them, for example, is a listing of government patents available for licensing. There is also the Smithsonian's Science Information Exchange. We use all of these. There have been cases where we have taken government research and put it into products, but there has never been a case where the initial contact came out of any of these formal efforts. It came out of scientific journals, contacts at meetings, or our salesmen happening to meet with a researcher and finding out about what he was doing. These formal technology transfer programs are not very cost-effective. I think, if you talked to people in universities or in the research corporations who try to license patents, they would tell you that it's a very costly process with low yield. I do not know where you got that thirty to one investment return ratio that you mentioned earlier.

Congressman Watkins: That is for NASA itself, which is the only agency with a mission of technology transfer. We are trying to organize the federal laboratory consortium to centralize that information and make it available by computer. If we do not get it to you and to others, it is wasted taxpayer's dollars.

Dr. Margoshes: Yes, but if the NASA effort so far has not produced much return, furthering the program just means spending more money which does not produce a return. I am suggesting that some other mechanism has to be found. Now, your idea of setting up centers where small businesses can go with their problems may be better, if these centers are organized to start with a problem looking for a solution. The people here at MIT's Sloan School will tell you that this is always more effective than starting with the cure and looking for the disease.

Congressman Watkins: I agree with that, and I will talk to you at length later about what we are trying to do in that area. I think you will find it interesting.

David Noble: I would like to make another observation. People are always saying, "Historians will write." Let me tell you what, as an historian, I would write about what I have seen today. I have been following this debate very closely, and I have read all of the hearings of Congressman Watkin's committee for the past few years. I am convinced now -- and I was not convinced before this conference -- that we are not talking here about innovation at all. The issue of university-industry cooperation is a side show, although a very important one. The concerns about innovation expressed here, although very significant and I share them, are a side show. These discussions and this conference are really all part of an industrial campaign to roll back the progressive legislation developed in the past fifteen years.

The real concern is to deregulate, and to change the tax laws, the patent laws and the antitrust laws. Above all it is a campaign to reduce uncertainty for investment; we have heard the phrase so much it is almost a chant. I just want to remind you that there are other uncertainties as well. There are uncertainties concerning occupational hazards that are very real, and uncertainties about real and growing environmental hazards. We have not even scratched the surface of these at this conference. (I do not know if you have read the Boston newspapers during the past two days of the Conference, but we have a serious hazardous waste problem in Woburn right now.) Then there are the uncertainties of plant relocation, people in cities losing their jobs, their plants, their communities. There is technological unemployment with the implementation of CAD CAM systems and the like, which I think will become very significant; I think also that the labor movement in the United States will catch up to the labor movement in Europe in its concern about this. I add to this the gravest uncertainty of all: the possibility of war, which increases with every increase in the DOD budget, including a hike in R & D.

I think there is a trade-off to be made here among these uncertainties -- and we have been talking only about a particular type of uncertainty thus far, that affecting investment. I do not think that the other uncertainties will disappear, and I implore you to keep them in mind during this self-serving rush for cooperative innovation. If I did write a history of this conference, I would call it "The Myth of Progress, Revisited." The myth obscures the reality, and at great social cost.

Mr. Colton: I would like to respond to a couple of the previous questions and comments to alleviate some fears. It was suggested that we may be robbing Peter to pay Paul by funding centers rather than basic research. I might comment that the funding for centers is independent of that for basic research, at least at the National Science Foundation, and that basic research at the NSF is increasing by about twenty to twenty-five percent in FY81. So there is, at least from that standpoint, no conflict.

Another comment was that we ought to examine the whole innovation process, because it is a very important thing. If we do observe it, we will find that there are many components of it that need assistance. In fact, this kind of close examination has been going on for about three or four generations now, and we have found that if we were to fund all of the areas in the innovative process that need funding we would not have enough money to go around. We can either do nothing, or try to select some areas that we think are of major importance, and at the same time establish semi-quantitative measurements to determine any effects from increased funding. I would remark, in answer to the question that Professor Noble raised, that we have done quite a bit of studying. We ought to do more studying, but I think it is time we started some specific, active programs in certain areas. It may turn out that the centers program is one of those areas that may have a synergistic effect.

Prior to becoming President of Exxon Research and Engineering Company in 1977, **Dr. Edward E. David, Jr.** was Executive Vice President of Gould, Inc. From 1970 to 1973, he was Science Advisor to President Nixon, and prior to 1970, he was Executive Director of Research, Communication Principles Division of the Bell Telephone Laboratories.

Dr. David received his doctorate from MIT in 1950 and joined Bell Laboratories shortly after that. He holds seven honorary degrees, has received numerous awards, and is a member of the National Academy of Sciences and the National Academy of Engineering. David is chairman of the boards of the American Association for the Advancement of Science and of The Aerospace Corporation, and he is also on the Executive Committee of the MIT Corporation Board.

Mr. John H. Gibbons has been Director of the U.S. Congress' Office of Technology Assessment since 1979. Prior to that, and since 1954, Mr. Gibbons was both a group leader and a program director at the Oak Ridge National Laboratory, was director of the Federal Energy Administration's Office of Energy Conservation, and was professor of physics and director of the Energy, Environment and Resources Center at the University of Tennessee.

Mr. Gibbons has served on several advisory and working committees, including those of the National Academy of Science, the National Science Foundation and the National Bureau of Standards. A member of several boards of directors in the past, at the time of this conference he was part of the board of directors and chairman of the Energy Committee and the National Advisory Council of the Knoxville (TN) Energy Expo 82.

Mr. Gibbons is a fellow of the American Association for the Advancement of Science, the American Physical Society and several professional societies. He was awarded the Federal Energy Administration's Distinguished Service Award in 1974. Holder of an honorary Sc.D. from Randolph-Macon College, he received a B.S. in mathematics and chemistry from Randolph-Macon in 1949 and a Ph.D. from Duke University in 1954. A seasoned editor and writer, Mr. Gibbons has published more than fifty articles in the areas of energy and environmental policy, energy supply and demand, conservation, technology and policy, resource management and environmental problems, nuclear physics, and origins of solar system elements.

Richard M. Cyert is president of Carnegie-Mellon University. He began his career at Carnegie-Mellon in 1948 as an instructor of economics and climbed the academic ladder to become a full professor and head of the industrial management department. He became dean of the Graduate School of Industrial Administration in 1962 and served in that capacity until he became president in 1972.

Dr. Cyert received his bachelor of science degree from the University of Minnesota and his Ph.D. from Columbia University. He has received fellowships from the Ford Foundation and the Guggenheim Foundation.

Frequently quoted in national publications from the New York *Times* to the Washington *Post*, Dr. Cyert has authored or co-authored seven books and over seventy papers in the fields of accounting, behavioral science, economics and management. His *Behavioral Theory of the Firm* has been used extensively in colleges and universities in this country and abroad. Internationally recognized for his studies in economics and management science, Dr. Cyert has served as a consultant in these fields in Belgium, Germany, and Australia. The University of Gothenburg in Sweden and the University of Leuven in Belgium have given him honorary degrees in recognition of his contributions.

Dr. Cyert has been a director and consultant for many businesses and non-profit associations, including American Standard Inc., Allegheny International, Lord Corporation, and the First Boston Corporation. Among his many civic duties he is a trustee of Presbyterian-University Hospital, and a director of the Pittsburgh Symphony Society. In 1980, he was appointed to head Governor Richard Thornburgh's Tax Commission, a statewide group of citizens selected to review Pennsylvania's tax laws.

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